Fall 1980

Ceramic to Metal Bonding

Spencer A. Marrese
Marquette University

CERAMIC TO METAL BONDING

BY

SPENCER A. MARRESE

An Essay Submitted To The Faculty
Of The Graduate School,
Marquette University,
In Partial Fulfillment Of The Requirements
For
The Degree Of
Master Of Science
In
Mechanical Engineering

Milwaukee, Wisconsin
November, 1980

TABLE OF CONTENTS

ABSTRACT

Various theories for ceramic to metal bonding are discussed. Theories prior to the mid-1960's are categorized as either mechanical or chemical in nature with the main emphasis being a bibliography of articles on the topic which have been listed as appendices. Current theories are discussed as they relate to a Battelle Memorial Institute study conducted in the late 1950's.

Major factors affecting the ceramic-metal interfacial region, as related to surface or firing changes, are reviewed from current research.

Several possible directions to conduct future study are listed.

ACKNOWLEDGEMENTS

This is to express my sincere thanks to the many people who have played a part in my Master's program and this essay.

Thanks to Dr. Hirthe for his guidance throughout my Master's Degree Program, as my advisor and chairman of my review committee, and to Dr. Fournelle and Dr. Matar as review committee members. Thank you to Mr. Jim Sullivan and Mr. Dave Kramer for their help in finding sources of information and review of the essay; to Mr. Larry Medley for his work in the primary data search, and to Josephine LaValle for her help in typing of the essay.

Thanks also to the Briggs and Stratton and A. O. Smith corporations for their financial support.

And, finally, a special thanks to my wife, Honoré, for her patience throughout my program and help in organizing the appendix material of the essay.

TABLE OF ILLUSTRATIONS

BACKGROUND, DESCRIPTION AND DEFINITION OF CERAMIC TO METAL BONDING

The process of applying ceramic materials to metallic materials has been accomplished since ancient times, yet no universally accepted explanation has been proposed to date for the mechanism which causes this phenomenon. The major reasons for the lack of concrete evidence on how a ceramic can be made to bond to a metal appears to be, first, because of the many factors critical to achieving such a bond,[1] second, the fact that the simple mechanical theories (which will be discussed later) have been disproven, both by experimental and analytical methods,[2] and, third, because equipment capable of answering many questions about the materials after bonding has not been available until fairly recent years.[3]

Some of the factors involved in the ceramic-to-metal bond which will be discussed, in addition to compositional changes in both materials, include physical and chemical surface changes in the metal and changing parameters in the furnace during firing of the ceramic onto the metal surface. The complexity and certainty of the research describing physical and theoretical chemical effects of changing these parameters on the strength of the bond has, to a large extent, been dependent on the equipment available.

A simple progression of the research equipment to try to discover the mechanism of bonding has lead from the light microscope in the eighteen and early nineteen hundreds, to the x-ray diffraction equipment of the early 1900's, the electron microscope of the 1940's and 1950's, to the use of their present day counterparts, along with current dispersive x-ray, scanning electron microscope, electron and ion microprobe, etc.[4] As can be seen from this list of current equipment used to help determine the bonding mechanism, although the problem has remained the same, the techniques for analysis have become much more complex.

Along with the complexity in research techniques has come more complex theories for the bonding mechanism. However, throughout this essay, the definition used for ceramic to metal bonding will be simply "any attractive force between ceramic and metal materials." This simple definition does not imply that the mechanism itself is of a simple nature, but, rather, that it is of a very general nature. There have been several theories to describe the underlying mechanism of the bond, however, the major intent of this essay is not to present a historical record but, rather, a present day listing of theories.

PURPOSE OF THE ESSAY AND INTENDED AUDIENCE

The purpose of this essay is to conduct a literature search and review of current literature on the theories and practices of ceramic to metal bonding. The information is intended for those people knowledgeable in ceramic sciences or ceramic engineering. No detailed explanations of the underlying chemical reactions presented, or modes of operation of various test equipment, will be given.

SOURCES OF INFORMATION AND LIMITATIONS OF THE ESSAY

Several data sources have supplied initial abstracts on the presently available periodical and research literature on the topic. Sources which were searched for information include ismec-mech. engineering, compendex, excerpta medica, bioscience previews, and weldindex data bases.

After reviewing the listing of abstracts, pertinent articles were gathered. Then, from the source articles, a review of their references was conducted.

Along with the periodical review, local libraries were also searched for books on the topic.

However, the essay is not intended as an exhaustive review of all written literature. Therefore, those articles which were not reviewed but are pertinent to the topic are listed in the appendices.

It must also be acknowledged that the author makes no claims of a specialized knowledge in the ceramic sciences through personal research on the topic, but is only reporting the ceramic to metal bonding theory as interpreted by researchers who have conducted such work.

One additional limiting factor on such a literature study is that, due to the highly technical nature of the topic and the value bonding information may have to manufacturers of products using this technology, a certain amount of material has not been published. This material is either being held in confidential company reports or for sale by consulting companies who have done research on the topic.

MAJOR TOPICS

The major topics of this essay review the reported theories of ceramic to metal bonding and the effects of changing test parameters on the bond.

REPORTED THEORIES OF CERAMIC TO METAL BONDING

The topic of ceramic to metal bonding has a long historical background which has consisted of periods of extremely high interest in the topic, linked together by periods of more moderate interest. After several of the peak research periods on the topic, review and/or comparison-type publications have been written so that now most of the roughly 400 articles prior to the mid-1960's can be traced through these summaries.[5] The articles present several theories to describe the underlying mechanism of ceramic to metal bonding, however, it is not the major intent of this essay to present a lengthy historical report, but rather a present day listing of theories. Keeping this intent in mind, only a short review of older theories will be given, with the main emphasis being a listing of articles by their general theoretical model in the appendices.

Several of the theories have been given specific names which describe the result of reactions occurring during the firing cycle, but, in general, all theories can be categorized as mechanical or chemical in nature. Mechanical theories are those having to do with mechanical interlocking or keying of the ceramic and metal. Chemical theories are governed by either ionic, covalent, or metallic bonding mechanisms.

In the mechanical bond, the narrowest cross sectional area of the glass keys is the controlling strength factor, while the chemical bond is controlled by the theoretical strength of the elements or compounds forming the bond.[6]

Table 1 lists specific theories along with a brief description of each. Theories are categorized as either mechanical or chemical in nature, depending on how the original author views the bonding mechanism. For example, Figure 1 shows a schematic representation of the galvanic corrosion theory of bonding.

The original author's interpretation is that after the corrosion of the metal surface has taken place, the bonding mechanism is the mechanical keying of the ceramic into the holes which have been formed. Therefore, the theory is categorized as mechanical, however, it has not been disproven that the actual mechanism is really some form of chemical bond. In reality, the bond may be between the oxygen in the glass and the cobalt, which in turn is chemically bonded to the iron.[7]

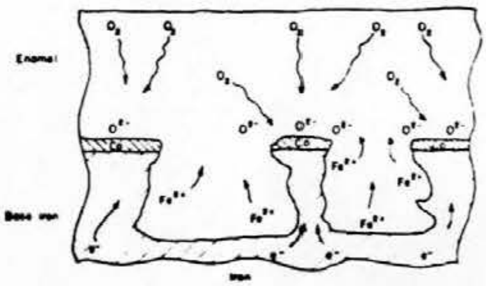

Fig. 1. Schematic presentation of galvanic corrosion in cobalt oxide-bearing ground coat as theorized by Dietzel.

Source: B. W. King, et al, "Nature of Adherence of Porcelain Enamels to Metals," Journal of American Ceramic Society, Vol.42, No. 11, November, 1959, p. 505.

TABLE OF BONDING THEORIES

Table 1

Theory	Description
MECHANICAL:	
Gripping	The ceramic bonds to the metal because of surface roughing by etching or blasting, which gives irregularities to which the enamel can hold.[8]
Dendritic	Dendrites formed by the reduction of iron or the growth of iron crystals at the interface serve as projections to hold the enamel to the iron.[9]
Electrolytic or Galvanic Corrosion	Metal oxides dissolved in enamels are reduced, during firing, to the metallic state by the base metal to which the enamel is applied. On the assumption that metals higher in the electromotive series displace metals lower in the series in solution of molten glass in much the same manner as they do in aqueous solutions, the adherence promoting metal is believed to form shorted localized galvanic cells which strongly corrode the base metal. The molten ceramic then develops a mechanical bond by penetrating the resultant cavities and by gripping the surrounding projections.[10]
CHEMICAL:	
Oxide Layer	An oxide layer between the ceramic and the metal is responsible for the bond.[11]
Hydrogen Reduction	The oxide of cobalt is a sacrificial material in that it is reduced to cobalt by the hydrogen to permit an intimate contact and adherence of the ceramic to the metal.[12]
Atomic Attraction	Any ceramic which contains a large amount of the lowest valence oxide of the metal to which it is applied, at the interface adheres to the metal.[13]
Electrochemical or Ionization	All metals iron through copper in the electromotive series will plate iron. These platings are then believed to form the bond between the enamel and the iron.[14]

In fact, other investigations have taken previously believed mechanical theories and proposed through essentially the same physical occurrence a different theory based on a chemical bonding.[15] Therefore, when compiling information on the historical advancement of a bonding theory from older publications for determining how it relates to current theories, care must be taken in noting whether the various authors are using a mechanical or chemical nature as a basis for the theory.

THEORIES PRIOR TO MID-1960'S

The mechanical theory was mainly predominant when the equipment available for analyzing samples were the light microscope and/or x-ray diffraction. The experiments would show the surface of the metal before firing as being either smooth or rough and an after firing comparison, but could not tell on an atomic scale what the compounds or elements in contact were after firing.[16] The major result seems to be whether or not the two materials were keyed together.

Articles by researchers who have reported on the various mechanical bonding theories are listed in Appendix A.

The chemical theories are concerned with the materials in contact at the intereface between a ceramic and a metal having a capacity for either of the known chemical bonding mechanisms as previously mentioned. Therefore, the theories try to show, either analytically or through experimental results, the appropriate chemical, thermodynamic, and/or kinetic reactions to accomplish the bond. Articles by researchers who have reported on the chemical nature of the bond are listed in Appendix B.

Major review or comparison articles for much of the older work are:

1) "Further Data on Enamel Adherence" by Karl Kautz, which summarizes the gripping, electrolytic, dendritic and oxide layer theories up until 1936.

2) "Mechanics of Enamel Adherence" by R. M. King, W. K. Carter, J. M. Cayford, W. L. Honsley, W. C. Rueckel, which is a series of seventeen articles on both mechanical and chemical aspects of bonding from 1930 to 1945.

3) "Fundamentals of Glass to Metal Bonding" by V. F. Zackay, D. W. Mitchell, S. P. Mitoff, J. A. Pask, and R. M. Fulrath, which is a series of eight articles mainly on the chemical theories of bonding from 1953 to 1962.

4) "Nature of Adherence of Porcelain Enamels to Metals" by B. W. King, H. P. Tripp and W. H. Duckworth, which summarizes the dendritic, electrolytic, galvanic corrosion or oxide layer theories up until 1959.

CURRENT THEORIES

No generally published review or comparison articles or literature covering the last approximately fifteen to twenty years of work on the topic has arisen in the present literature search. A possible reason for a lack of new theories or reviews of the literature over these more recent years may have to do with the wealth of information contained in the fourth review article listed above. The background research for the article, "Nature of Adherence of Porcelain Enamels to Metals", is an extensive review and summary of past theory, plus a large volume of new research work, which was done by the Battelle Memorial Institute.[17]

Because of the vast source of data which the article contains, and the use of standardized comparison techniques, it has, and continues to form the basis for a significant amount of subsequent research.

The four major conclusions of the study are:[18]

1) The ceramic must wet the metal and that the bond developed between porcelain enamels and metals is essentially chemical in nature.

2) Good adherence requires that the ceramic at the interface be saturated with an oxide of the base metal, and that this oxide must not be readily reduced by the metal.

3) Good adherence of ceramics to metals appears to be the result of metal-to-metal bonding between the atoms in the base metal and metallic ions in the ceramic when certain chemical and thermodynamic requirements are met.

4) The oxides commonly known as adherence promoters help to establish and maintain the conditions necessary for good adherence without contributing directly to the bond developed.

Theory on the structure of the bond was on work done on the solubility of FeO in enamel type ceramics. At the solubility limit, the ceramics probably have an unusual structure because the glass forming ions and the oxygen ions which can be assigned to them are in such proportions that, on the average, only continuous chains can be formed. An example of this explanation is shown in Figure 2.

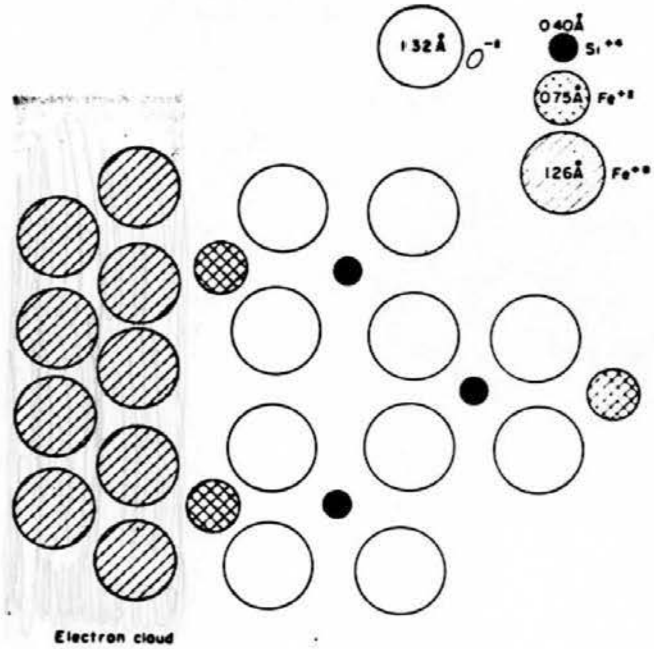

Fig. 2. Schematic representation of ceramic-iron interface.

Source: B. W. King, et al, "Nature of Adherence of Porcelain Enamels to Metals," Journal of American Ceramic Society, Vol. 42, No. 11, November, 1959, p.523.

For determining approximate solubility of FeO in different borosilicate ceramics, factors were derived from the solubility curves which were generated by adding FeO to glass batches until metallic iron or wüstite appeared. Table 2 is a listing of the solubility factors which were found.

Table 2. SOLUBILITY FACTORS FOR FeO

Oxide	Factor
Na_2O	-0.63
K_2O	-0.45
CaO	-0.40
BaO	-0.11
MgO	-0.92
MnO	-0.00
Al_2O_2	-1.21
TiO_2	-1.34
ZrO_2	-0.75
B_2O_3	+1.70
SiO_2	+1.20
P_2O_5	+2.23

Source: B. W. King, et al, "Nature of Adherence of Porcelain Enamels to Metals," Journal of American Ceramic Society, Vol. 42, No. 11, November, 1959, p.514.

To obtain the FeO solubility, multiply the weight percentage of oxide in the glass by its factor, and add algebraically the products. A negative value means that glass can dissolve no FeO. A positive value indicates solubility in parts of FeO in 100 parts of glass at 1600^{0}F, then thermodynamically the oxides should react with the FeO to form an Fe_3O_4 compound which, in turn, dissociates to Fe^{3+} and, finally, by the following reaction, form Fe^{2+}, which causes the metal-to-metal bond at the ceramic-iron interface:

$$4\ Fe^{3+} + 2\ Fe^{0} \longrightarrow 6\ Fe^{2+}$$

The significant result of the adherence promoters forming Fe_3O_4 is that Fe_3O_4 has a greater rate of solubility than other forms, such as FeO or Fe_2O_3, as is predicted by the general kinetic formula for the rate of solution of an ideal solute in an ideal solvent as follows:[19]

$$dx/dt = K\ (C_L - X_X)$$

where:

dx/dt	=	rate of solution of a solute x at any given time t.
K	=	a constant depending on agitation, diffusion, etc.
C_L	=	concentration of solute at the limit of saturation
C_x	=	concentration of solute at time t.

Therefore, with the aid of the adherence promoters, an oxide is established which is more readily soluble. Then the oxygen, which was shown to be the primary corrosive agent, can begin its action sooner to allow the metal to metal bonds to form.

Douglas and Zander helped confirm with the use of x-ray diffraction that glass applied to nickel flashed sheet iron formed Fe_3O_4 which is in agreement with the Battelle report.[20]

Most of the work being done more recently is with the aid of the scanning electron microscope, electron microprobe, energy dispersive x-ray, x-ray diffraction, Auger electron microscope and/or microprobe. Through the use of this highly sophisticated equipment, more accurate identities of the materials in the interfacial region between ceramics and metals are leading to a better understanding of the bonding mechanisms.

Dr. Arsenize Nedeljkovic has, with the use of such equipment, reported on:[21]

1) The role of nickel at the ceramic-metal interface.
2) The composition of the interfacial region of titania direct-on cover enamels.
3) Structural differences at the interface of cobalt versus nickel containing glasses.

And Dove, with the aid of the Auger electron microscope and ion microprobe, has reported on the "Chemical Profile of Oxidized Nickel Films."[22]

Although much of the recent work has still not led to a generally accepted bonding theory, it has helped to accurately specify the compounds present in the bond area, which, in turn, brings a more thorough understanding of the effects of changing test parameters.

EFFECTS OF CHANGING TEST PARAMETERS ON CERAMIC TO METAL BONDING

Setting theory aside, much of what is done in the manufacture of products which require ceramic to metal bonds is done simply because it works. And, once again, just as a theory for the bonding mechanism has been illusive, so has a universal test of ceramic to metal bonding. Impact tests using falling weights or pendulums, deformation tests involving bending, torsion, compression, or tension, and even kinetic, electrical, and microscopic tests have all had their turn in saying whether the bond was working.[23] Therefore, also setting a standardized test for bonding aside, several of the critical parameters in the bond will be discussed.

One researcher has listed the critical factors in the bond in order of importance as:[24]

1) Base metal composition
2) Metal surface preparation
3) Enamel composition
4) Mill additions
5) Furnace atmosphere
6) Firing temperature
7) Heating rate
8) Cooling rate

For simplicity of presenting information in a general form, the above factors will be combined into two variables, surface changes and firing changes; surface changes being defined as changes involving any of the first four factors, and firing changes involving the last four factors.

SURFACE CHANGES

The effect of using a relatively low strength decarburized enameling steel in the 0.002% to 0.004% carbon range, compared to a 0.1% to 0.2% carbon steel fired at 1500^{o}F. is that the higher carbon steel will undergo the alpha to gamma iron transformation when the low carbon steel will not. The result of the transformation being:

1) An increase in the capacity of the steel to hold hydrogen from the furnace atmosphere which may, upon cooling, lead to surface defects in the ceramic.

2) Thermal expansion problems in the steel to glass interface during the transformation which may cause cracking or crazing of the ceramic.

Ways of preventing the hydrogen problems are to use a gritblasting instead of pickling surface preparation and to apply an oxide film on the steel prior to the ceramic to prevent hydrogen penetration. In addition, a slow cooling rate to allow the steel to go back to the alpha phase before solidifying the ceramic is reported to help the crazing problem.[25]

In the case of some stainless steels, such as Series 300, the alloying elements can suppress the gamma to alpha transformation so that it does not occur upon cooling, thereby eliminating the transformation expansion problem. However, due to the relatively high coefficients of expansion of these stainless steels, a ceramic also with a high coefficient of expansion must be used to satisfactorily bond with the metal.[26]

Coating a variety of other metals was done by researchers from Battelle to confirm their conclusions as previously stated. The results were that they obtained appreciable adherence with a relatively standard ceramic on the following metals:[27]

Cu, Zn, Sn, Cr, Co, U, Ag, Al, Pb, Mo, Rh, Br, Si, Sb,
W, Ni, Mg, Ti, Ta, Mn, Pd, Ca, Zn, Bi, Fe, Pf

In the Battelle study, it was demonstrated that an important prerequisite for bonding was the wettability of the ceramic on the metal; the condition of good wettability being related to a low interfacial tension of the ceramic and metal.

From the experiments which were performed, the following factors were shown to either promote or deter wettability.[28]

Factors which generally promote or maintain wettability:

1) Additions of oxides whose free energy of formation are less than ferrous oxide (FeO) with the exception of PbO and Bi_2O_3.
2) Increases in the cobalt oxide content of the ceramic.
3) Increases in the ferrous oxide content of the ceramic.
4) Increases in furnace oxygen.

5) Increases in glass former content of the ceramic
6) Maintenance of an oxide layer on the metal surface
7) Additions of oxide additions in the form of adherence promoters

Factors which generally deter wettability:

1) Oxide-free metal surface
2) Excessive oxide content of ceramic due to crystalline material
3) Excessive reducible oxide content
4) Increases in glass-modifier content of the ceramic

The effect of wetting on good bonding is not, however, an iron-clad requirement, as noted by other researchers who have claimed that, "Poor wetting is not necessarily an indication of poor /bonding/. However, systems with /good wettability/ generally develop a strong chemical bond."[29]

Changing to the question of the effect surface roughness of the metal has on bonding; many different conditions experimentally and analytically, as shown in a review of Appendix A, have been written on this mechanical theory.

Relatively recent research and analytical methods of estimating mechanical to chemical bond strengths have both shown this mechanism to be of relatively minor importance in directly contributing to the bond strength.[30] The value of the surface roughening, instead, is possibly to give a greater specific surface area which can help develop satisfactory bonding by lowering the required unit bond strength.

How the surface factors ultimately affect bonding is influenced by changing firing parameters as was already indicated in the prior brief discussions of O_2 in the furnace atmosphere and the cooling rate on gamma-alpha transformations in steels.

FIRING CHANGES

Assuming that the contact angle of the ceramic to the metal interface is a true indicator of wettability of the ceramic to the metal, and in turn that wettability does lead to bonding, experiments have shown that:[31]

1) Oxygen or other surface-adsorbed gases are of primary importance in determining wetting characteristics.

2) Temperature of firing does change the contact angle. Figure 3 is a plot of contact angle of a fairly common ceramic on platinum during heating and cooling cycle.

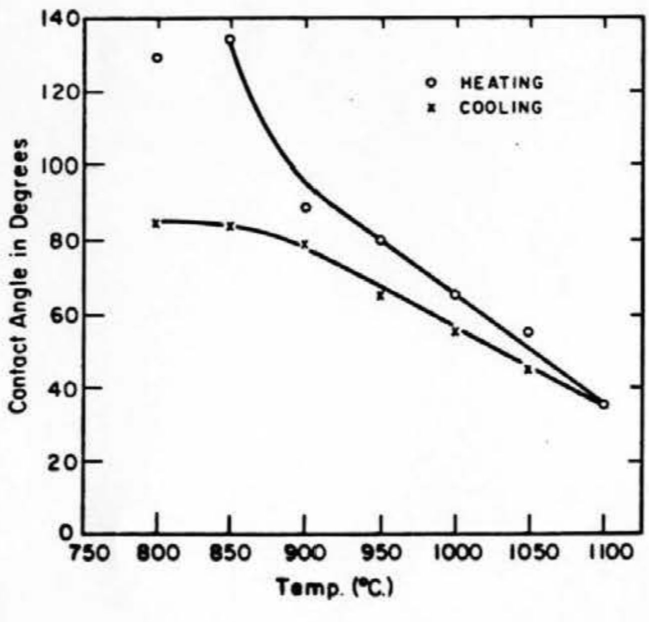

Figure 3. Contact angle vs. temperature of $Na_2O \cdot 2SiO_2$ glass on platinum.

Source: Richard M. Fulrath et al, "Fundamentals of Glass-to-Metal Bonding: III, Temperature and Pressure Dependence of Wettability of Metals by Glass," Journal of the American Ceramic Society, Vol. 40, No. 8, August, 1957, p. 271.

The corresponding definition of the contact angle for the ceramic-metal interface is shown in Figure 4.

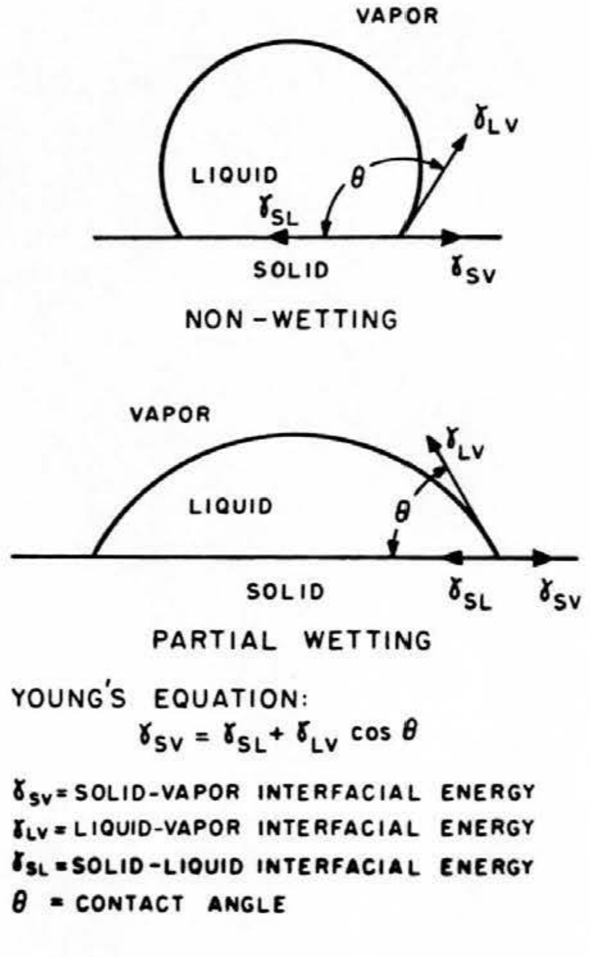

Figure 4. Equilibrium for small drops of a liquid on a solid.

Source: Richard M. Fulrath et al, "Fundamentals of Glass-to-Metal Bonding: III, Temperature and Pressure Dependence of Wettability of Metals by Glass," Journal of the American Ceramic Society, Vol. 40, No. 8, August, 1957, p.269.

3) Pressure changes during firing will affect the contact angle (as defined in Figure 4) as follows:

   a) Low pressures normally imply high surface energies of the metal and lead to only partial wetting.

   b) At slightly higher pressures, surface energy is reduced but interfacial energies are still high so that again only partial wetting occurs.

   c) At still higher pressures, the interfacial energy decreases relative to the surface energy and greater wetting occurs.

Generally, however, it has been concluded as noted that, "the requirements for successful firing of ceramics are comparatively simple /compared to surface factors/."[32] Temperatures and times for firing materials with difference surface parameters have been known for some time, where the main criteria is to produce a smooth continuous glassy layer. And, aside from allowing for possible crystalline transformations in the metal, heating and cooling rates are not considered very important as long as a uniform part temperature is maintained.[33]

Although it is felt that firing parameters are secondary to surface parameters in the bonding mechanism, it must be remembered that the firing process is dynamic and that measurements of what happens during firing are not as easy to attain as "material-in, material-out" chemical analysis associated with the surface parameters. To illustrate some of the firing relationships, Figure 5 is a plot of various properties of a titanium cover coat enamel on steel during a twelve minute firing cycle, as reported by A. L. Friedberg.

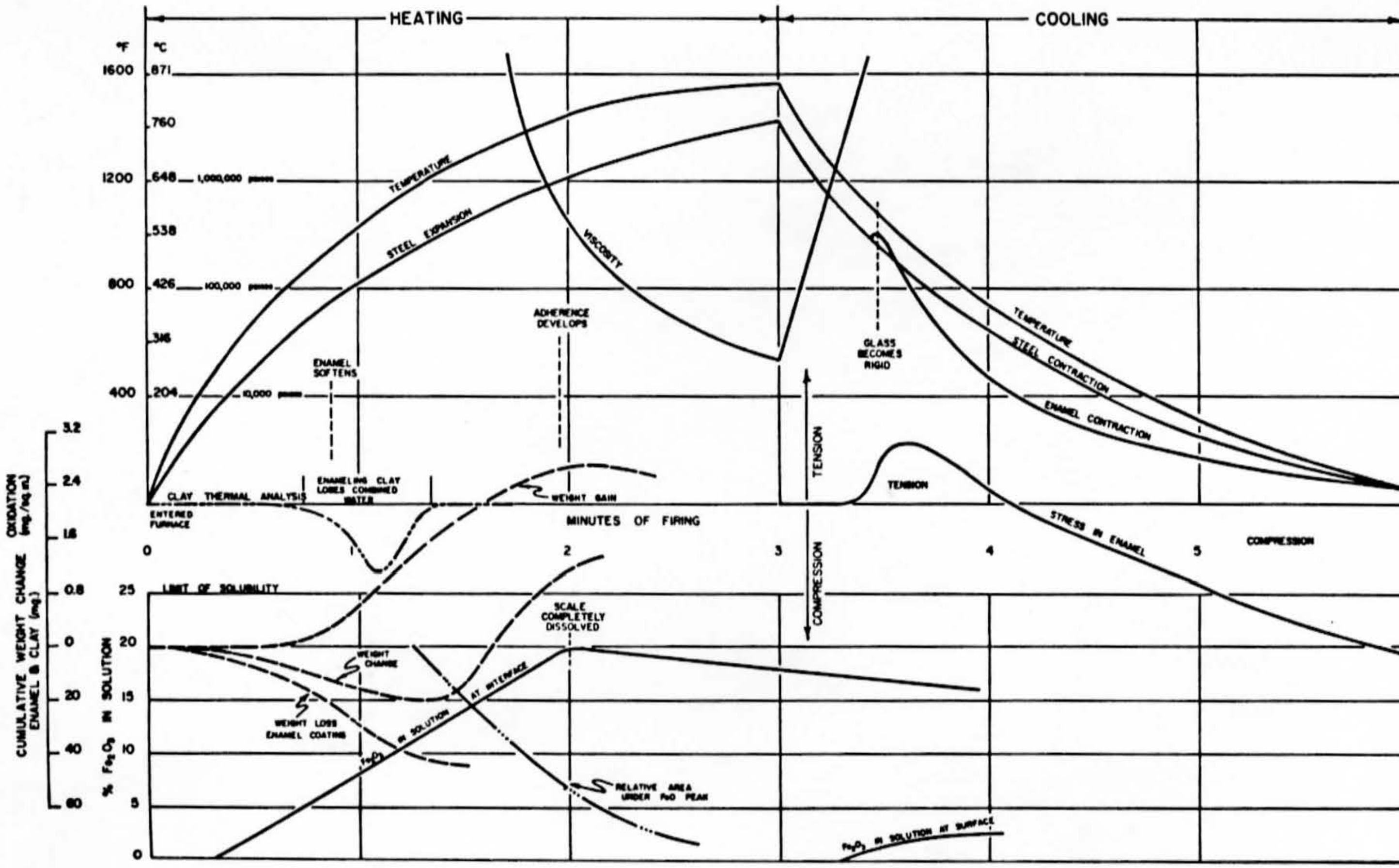

Figure 5. Cover coat firing.

Source: Andrew I. Andrews, Porcelain Enamels (Champaign, IL: Garrard Press, publisher, 1961), p. 427.

With the wealth of experimental data, physical observations, and analytical theories available on bonding and still no universal agreement, it appears that the next question to attempt to answer is, what to do next?

WORK TO BE DONE

Logical ways of determining what to do might be to:

1) Decide what ceramic-metal combinations are most used in industry. Collect past work on the use of these material combinations and re-conduct critical experiments using the new analysis equipment which is available to help reconfirm the theory;

2) Decide what ceramic-metal combinations may be used in the future in areas such as bone and joint surgery, and start from the most basic principles in conducting research;

3) Concentrate not on the more complex issue of a ceramic-metal bond, but instead, first do more fundamental work in gaining additional knowledge of the ceramic structure. This information, in turn being used as basis for better understanding the conductivity, transfer and bonding mechanisms;[34]

4) Work on attaining a more specific and quantitative application of the equations already presented through experimentation on the chemistry of ceramic-metal systems involving equilibrium constants, composition stabilities, and activity coefficients;[35]

5) Use present day equipment, such as the electron microprobe and scanning electron microscope to study a wider range of enamel compositions.[36]

Not all research decisions can be made from the standpoint of logic, however, and it appears that a controlling factor in determining which direction research for manufacturing companies will be pointed is in the hands of government agencies. Legislation such as the Clean Air and Hazardous Waste Acts have made it a foregone conclusion that a good share of available work from these sources will be concentrated on material substitutions for reducing or replacing lead, barium, cobalt and a host of other materials. It is only hoped that much of this work can also be applied to solving the basic problem of understanding the bonding mechanism.

Appendix A

Articles On Mechanical Theories Of Bonding

1. Aldinger, Richard, "Enamel Adherence," Ceram. Age, 21 163-5 (1933).

2. Belyaev, G. I., "Effect of Enamel Melts on Steel", Zhur Prikland Khim., 30(7) 1077-80 (1957).

3. Berk, Jan and de Jong, Jan, "Adherence of Porcelain Enamel to Sheet Steel", J. Am. Ceram. Soc. 41(8) 287-92 (1958).

4. Clawson, C. D., "A Study of Adherence of Ground Coats to Sheet Steel", Ceram. Ind., 13(2) 164-66 (1929).

5. Cole, Jr., S. S. and Sommer, G., "Glass-Migration Mechanism of Gromic-to-Metal Seal Adherence", J. Am. Ceram. Soc., 44(6) 265-71 (1961).

6. Deringer, W. A., "Relation of Hydrogen to Adherence of Sheet-Steel Enamels", Jour. Amer. Ceram. Soc. 26 151-159 (1943).

7. Dietzel, A. and Meures, K., "Adherence of Base Coat of Enamel to Iron", Sprechsaal, 66 647-652 (1933).

8. Dietzel, A., "Explanation of Adhering Problem in Sheet-Iron Enamels", Emilwaren-Ind. 11(19) 161-166 (1934).

9. Dietzel, A., "Adherence of Sheet-Iron Enamel", Glashutte, 64 646-48 (1934).

10. Dietzel, A., "The explanation of Adherence Problems for Sheet-Steel Enamels", Sprechsaal, 67 265 (1934).

11. Dietzel, A. and Meures, K., "Reactions Important for Adherence When Firing Ground Coats Containing No Adherence-Promoting Oxides", Jour. Amer. Ceram. Soc. 18 35-37 (1935).

12. Dietzel, A., "Explanation of the Adhesion Problems in Enameling Iron Sheets", Sprechsaal, 68 3-6, 20-23, 24-27, 53-56, 67-69, 84, 85, (1935).

13. Dietzel, A., "Molybdenum in Enamels" Enailwaren-Ind., 18 (13, 14) 30-31 (1941).

14. Dietzel, A., "Systems of Sulphide, Selenide, Telluride Pigments in Glass", Glastech Ber. 19 4-8 (1941).

15. Dietzel, A., "Theory of the Adherence of Enamel to Iron", Keramik, 78 (5-8) 19-20 (1945).

16. Dietzel, A., "Theory of the Adherence of Enamel to Iron", Keramik (formerly Sprechsaal), 75 (5-8) 19-20 (9-12) 34-36 (1945).

17. Dietzel, Adolf, "Reaction and Adherence Between Glass and Metal in Seals", Glastech, Ber. 24(11) 263-68 (1951).

18. Eyer, P., "Enameling Iron Articles", U. S. Patent 2,016,322 (Oct. 8, 1935).

19. Haras, B., "The function of the Ground Enamel", Sprechsaal, 44 72-73 (1911).

20. Hayes, Anson, "Fundamental Factors Contributing to Adherence of Enamel", Better Enameling, 4(1) 6-8 (1933).

21. Healy, J. M. and Andrews, A. J., "Cobalt-Reduction Theory of Sheet-Iron Enamels", Finish, 7(12) 22-23 (1950).

22. Heims, Freidrich, "Adherence of Ground Enamels Containing Cobalt and Nickel Oxides", Sprechsaal, 67 231-232 (1934).

23. Heims, Freidrich, "Adherence of Ground Enamels Containing Cobalt and Nickel Oxides, II", Sprechsaal, 67 720-722 (1934).

24. Housley, W. L. and King, R. M., "Mechanics of Enamel Adherence, XI. Application of the Theory of Dendritic Adherence to the Development of White Ground Coats", Jour. Amer. Ceram. Soc. 18 319-320 (1935).

25. Howe, E. E. and Fellows, R. L., "Effect of Manganese, Nickel and Cobalt Upon the Adherence and Reboiling Properties of a Ground Coat Enamel", Jour. Amer. Ceram. Soc. 20 319-324 (1937).

26. Howe, E. E., "Observations on the Adherence Phenomena of Sheet-Iron Ground Coats", Better Enameling, 9(9) 13-19 27-29 (1938).

27. Hull, A. W. and Burger, E. E., "Glass-to-Metal Seals", Jour. Applied Phys., 12(9) 698-707 (1941).

28. Hull, A. W. and Burger, E. E. and Navias, L., "Glass to Metal Seals", Jour. Applied Phys., 12(9) 21-22, 52 (1947).

29. Kautz, Karl, "Further Data on Enamel Adherence", Jour. Amer. Ceram. Soc., 19, 93-108 (1936).

30. Kautz, Karl, "Discussion of Lord Paper", Jour. Amer. Ceram. Soc., 19, 93-108 (1936).

31. Kautz, Karl, "Reply to Staley's Discussion of Lord and Kautz Paper's", Jour. Amer. Ceram. Soc., 21(9), 311-315 (1938).

32. Keiser, W., "Adhering Oxides", Keram. Rundschau, 41, 228 (1933).

33. Kerkmann, J. and Kerkmann, H., "Enamel Glaze", German Patent 290,054 (Nov. 4, 1913).

34. King, R. M., "The Adherence of Glass to Metals", Glass Industry, 23(11), 421-423, 440 (1942).

35. King, R. M., "Adherence of Porcelain Enamel Ground Coats", Metal Prods. Mfg., 14(6), 58-59, 62 (1957).

36. Knapp, W. J., Shah, C. C. and Planje, T. J., Wetting Properties of Enamels", Jour. Amer. Ceram. Soc., 33, 258-262 (1950).

37. Kreidl, Ignaz, "Enameling Iron", Austrian Patent 136,003 (Dec. 27, 1933).

38. Kreidl, Ignaz, "Enameling Iron", British Patent 421,171 (Dec. 14, 1934).

39. Kreidl, Ignaz, "Enameling Iron", Austrian Patent 140,849 (Feb. 25, 1935).

40. Kreidl, Ignaz, "Enameling Iron", German Patent 629,797 (May 12, 1936).

41. Kreidl, Ignaz, "Enameled Sheet-Iron Ware", U. S. Patent 2,109,436 (March 1, 1938).

42. Laszlo, Tibor S., "Mechanical Adherence of Flame-Sprayed Coatings", Am. Ceram. Soc. Bull., 40(12), 751-55 (1961).

43. Lord, J. O., "Critical Analysis of Some Statements and Experiments on the Adherence of Sheet-Steel Ground Coats", Jour. Amer. Ceram. Soc., 20(4), 111-114 (1937).

44. Mayer, M. and Havas, B., "Function of Ground Enamel", Sprechsaal, 43 737, 727-729 (1911).

45. Meyer, A., "Manufacture of Enameled or Glazed Plates of Iron or Steel", German Patent 272,355 (July 9, 1911).

46. Meyer, H. and Dietzel, A., "Flame Spraying of Ceramic Coatings", Ber. deut. Keram. Ges., 37(4), 136-40 (1960).

47. Moore, D. B., Pitts, J. W., Richmond, J. C., and Harrison, W. N., "Galvanic Corrosion Theory for Adherence of Porcelain Enamel Ground Coats to Steel", J. Am. Ceram. Soc., 37(1), 1-6 (1954).

48. Moore, D. G., Pitts, J. W. and Harrison, W. N., "Role of Nickel Dip in Enameling of Sheet Steel", J. Am. Ceram. Soc., 37(8), 363-69 (1954).

49. Nakanishe, Kenji, Nakagawa, Yoshifumi and Kitazumi, Ishio, "Studies on Enamel Free from Borax and Cobalt: II", J. Japan. Ceram. Assoc., 52(615), 101-104 (1944).

50. Patridge, J. A., "Glass-to-Metal seals", Soc. Glass Tech., Sheffield, P. 214 (1949).

51. Rosenberg, J. E., "Enamel Coatings on Iron Articles", U. S. Patent 2,043,559 (June 9, 1936).

52. Rosenberg, J. E. "Enamelware", U. S. Patent 2,086,190 (July 6, 1937).

53. Rosenberg, J. E., "One-Coat Enameled Iron Article of Red and Yellow Color", U. S. Patent 2,317,114 (April 20, 1943).

54. Rueckel, W. C. and King, R. M., "Mechanics of Enamel Adherence, II. Effect of Composition and Firing Atmosphere on the Adherence of Ground-Coat Enamels", Jour. Amer. Ceram. Soc., 14 782-8 (1931).

55. Schaarschuh, H., "Adherence of Sheet-Iron Ground Enamel", Glashutte, 63, 811-19 (1933).

56. Staley, Homer F., "Electrolytic Reactions in Vitreous Enamels and Their Relation to the Adherence of Enamels to Steel". Jour. Amer. Ceram. Soc., 17, 163-7 (1934).

57. Staley, H. F., "Discussion of Lord and Kautz Papers", Jour. Amer. Ceram. Soc., 20, 121-24 (1937).

58. Subbatao, E. C., "Theory of Adherence of Vitreous Enamels to Aluminum", Sci. Ind. Research (India) 15B(3), 150-154 (1956).

59. Vielhaver, L., "Attempts to Roughen the Sheet-Iron Surface", Emailwaren-Ind. 12, 71-2 (1935).

60. Vielhaber, L., "Enameling of Sheet Steel Without Prior Pickling", Mitt. Ver. deut. Emailfachleute, 4(8) 59-60 (1956).

61. Weyl, W. A., "The Replacement of Oxygen in Glass and Its Effect on Adherence", Glass Ind., 23(4) 135-8 (1942).

62. Weyl, W. A., "Adhesion to Glass", Glass Industry, 26(12) 557 (1945).

63. Yamada, Toshio, "Aluminum Enameling: III. Effects of Pretreatment of the Aluminum Surface by Anodic Oxidation on the Enameling", Vogyo Kyokai Shi., 68(774) 163-68 (1960).

64. Yamada, Toshio, "Studies on the Mechanism of Adherence of Aluminum Enamels---Observation of the Boundary Surface Between Enamel and Metal", Yogyo Kyokai Shi, 69(781) 29-33 (1961).

Articles On Chemical

Theories Of Bonding

1. Adams, R. B. and Pask, J. A., "Fundamentals of Glass-to-Metal Bonding: VII. Wettability of Iron by Molten Sodium Silicate Containing Iron Oxide", J. Am. Ceram. Soc., 44 430-3 (1961).

2. Aldinger, Richard, "Adherence of Enamel to Iron", Sprechsaal, 66(15), 251 (1933).

3. Aldinger, Richard, "Cooling Enameled Ware", Emailwaren-Ind., 10 246-8 (1933).

4. Aldinger, Richard, "Practical Results of Scientific Researches in Enameling", Glashutte, 66(9) 157-60 (1936).

5. Aldinger, Richard, "Development of Sheet-Iron Ground-Coat Enamels", Glashutte, 68 610-12 (1938).

6. Aldinger, Richard, "Low-Melting Enamels", Glashutte, 75 193-95 (1949).

7. Altmannsberger, K., "White Ground Coating", Sprechsaal, 63 762-3 (1930).

8. Amberg, Prior, and Richmond, "Adhesion of Enamel to Steel, Produced by Electrodeposition of $Mo(OH_3)$ on Steel", Jour. Amer. Ceram. Soc., 20 75-76 (1937).

9. Andrews, A. I., "A Systematic Method for Investigation of Sheet-Iron Enamels", Jour. Amer. Ceram. Soc., 13 489-97 (1930).

10. Andrews, A. I. and Swift, H. R., "Iron Oxide and Enamel Glass as Dissolved from a Metal Base", Jour. Amer. Ceram. Soc., 25 217-22 (1942).

11. Andrus, Joseph M., "Enameled Aluminum and Process for Manufacture Thereof", (Croname, Inc.), U. S. 2,991,234 (July 4, 1961).

12. Armstrong, W. M., Chaklader, A. C. D. and Clarke, J. F., "Interrace Reactions Between Metals and Ceramics: I, Sapphire-Nickel Alloys", J. Am. Ceram. Soc. 45(3) 115-18 (1962).

13. Athy, Lymann C., "Vitreous Enamels", British Patent 389,436 (March 16, 1933).

14. Athy, L. C. and Stufft, P. O., "Vitreous Enamels", U. S. Patent 2,361,376 (October 31, 1944).

15. Azarov, K. P., "Enameling Iron", Russian Patent 52,422 (Jan. 31, 1938).

16. Azarov, K. P. and Kharchenkora, N. S., "White Ground-Coat Enamel for Iron", Jour. Applied Chem. (U.S.S.R.), 12 1598-1600 (1939).

17. Badger A. E. and Bard, B., "Molten-Glass Reactions with Metals", Jour. Amer. Ceram. Soc., 23 326-8 (1940).

18. Baker, E. W., "Vitreous Enameling", Poor & Co. Brit. 664,394 (Nov. 14, 1951).

19. Bamford, C. R., "The Magnetic Behavior of Iron Transition Group Elements in Glasses, III. Iron in Sodium Silicate Glasses and the Sulphur-Amber", Phys. Chem. Glasses 2 163-8 (1961).

20. Bayer, E., "Boron-Free Sheet-Ground Enamels", Glashutte, 71 399-400 (1941).

21. Beall, F. W., Myers, R. L., and Canfield, J. J., "Etching Steel for Adherence of Porcelain Enamel", Am. Ceram. Soc. Bull. 39(12) 727-31 (1960).

22. Belyaev, G. I., "Influence of Alkali Metal Carbonates on the Properties of Ground Enamels", Steklo i Keram 15(3) 33-37 (1958).

23. Belyaev, G. I. and Smakota, N. F., "Effect of Iron Oxide on the Properties of Boron-Containing and Boron-Free Ground Enamels", Zhur, Prikland, Khim 31(12) 1792-99 (1958).

24. Belyaev, G. I., "Effect of Group II Metal Oxide on the Properties of Ground Enamels", Steklo i Keram., 17(4) 33-35 (1960).

25. Benjamin, P. and Weaver, C., "Adhesion of Metal Films to Glass", Proc. Roy Soc. (London) A25A (1277) 177-83 (1960).

26. Bennett, D. G. and Kimpel, Robert F., "Factors Affecting Oxidation of Iron During Firing of Porcelain Enamel Ground Coats", U. S. Air Force Air Material Command. A. F. Tech. Rept. No. 6076 20 pp. (Aug., 1949).

27. Berg, Morris and Humenik, Jr. Michael, "Contribution to the Theory of Enamel Adherence", Am. Ceram. Soc. Bull. 31(9) 329-31 (1952).

28. Bergeron, Clifton G., Friedberg, Arthur L., et al, "Protective Coatings for Refractory Metals", PB. Rept., 161739 50 pp. U. S. Govt. Research Repts.

29. Berndt, M., "The Status of Cobalt in Ground Coat of Sheet-Steel Enamels", Keram. Rundschau, pp. 262 (1914).

30. Beyerlein, K., "Action of Adhesive Oxides in Ground-Coat Enamels", Keram. Rundschau, 40 205-8 (1932).

31. Bishop, E., "Adherence of Vitreous Enamel to Arc Welded Mild Steel", Sheet Metal Inds., 26(268) 1755-60 (1949).

32. Bley, R. S., "Vitreous-Enamel Dispersions Suitable for Use on Metal", U. S. Patent 2,058,209 (October 20, 1936).

33. Bliton, Jerald L. and Rechter, Harold L., "Determination of Physical Properties of Flame-Sprayed Ceramic Coatings", Am. Ceram. Soc. Bull. 40(11) 683-88 (1961).

34. Blocher, Jr., J. M. and Oxley, J. H., "Chemical Vapor Deposition Opens New Horizons in Ceramic Technology", Am. Ceram. Soc. Bull., 41(2) 81-84 (1962).

35. Bose, H. N. and Kalrah, I. S., "Experiments on Ground-Coat Enamels", Indian Ceram., 1 92-9 (1938).

36. Brown, M. and Harr, R. E., "Enamel-Coated Telephone Dial", U. S. Patents 2,398,881 and 2,399,094, (April 23, 1946).

37. Bryant, E. E., "White Porcelain Enamel for Direct Application to Steel", U. S. Patent 2,414,633 (Jan. 21, 1947).

38. Budnikov, F. P. and Goldenberg, I. G., "Acidproof Enamels on Iron from Available Materials", Khimicheskaya Prom., (12) 14-14 (1945).

39. Canfield, J. J., "Copperheads or Iron Oxide Defects in Porcelain Enamels", Iron Age, 136(7) 30-34 (1935).

40. Capper, H., "Use of Gas in Vitreous Enameling", Ind. Gas (Engl.), 19 287-88, 315 (1956).

41. Carter, P. T. and Ibramin, M., "The Ternary System Na_2O-FeO-SiO_2", J. Soc. Glass Technol 36 142-63 (1952).

42. Carter, W. K. and King, R. M., "Mechanics of Enamel Adherence, III. Enamels on Copper--The Nature of Their Adherence", Jour. Amer. Ceram. Soc., 14 788-94 (1931).

43. Cavanagh, Walter R. and Maurer, James I., "Cold Cleaning and Cold Phospate Coating Process", (Parker Rust Proof Co.) U. S. 3,007,817 (Nov. 7, 1961).

44. Cayford, J. M. and King, R. M., "Note on the Relation Between Cobalt and Nickel-Oxide Contents on Reboiling on Sheet-Steel Ground Coats", Jour. Amer. Ceram. Soc. 18 224 (1935).

45. Cecil, Paul S., "White Porcelain Enamel Applied Directly to Steel in Hollow Ware and Lighting Fixtures", Proc. Porcelain Enamel Inst. Forum 12th Forum pp. 42-45 (1950).

46. Chester, A. E., "Enamel Coating for Ferrous Metals", Canadian Patent 423,320 (October 17, 1944).

47. Chester A. E., "Process Step for Enamel-Coating Ferrous Metals", Canadian Patent 423,321 (Oct. 17, 1944).

48. Chester, A. E., "Enamel Coating for Ferrous Metals", U. S. Patent 2,321,656 (June 15, 1943).

49. Chester, Allan E., "Vitreous Enameling of Ferrous Metal", (Poor & Co.), U. S. 2,510,071, June 6, 1950 (Aug. 9, 1945).

50. Chester, Allen E. and Schram, Jr. Irwin, H., "Vitreous Enamel Base Stock, Vitreous Enameled Articles and Method", (Poor & Co.) U. S. 2,569,453, Oct. 2, 1951 (Sept. 14, 1949).

51. Chester, Allan E., "Method of Bonding Vitreous Enamels", (Poor & Co.) U. S. 2,615,836, Oct. 28, 1952.

52. Chester, Allan E., "Vitreous Enameling Processes and Products", (Poor & Co.,) U. S. 2,639,264, May 19, 1953.

53. Chester, Allan E., "Vitreous Enameling Process", (Poor & Co.) U. S. 2,768,904 (Oct. 30, 1956).

54. Chester, Allan E., "Base Stock for Vitreous Enamel Coatings", (Poor & Co.) U. S. 2,963,784 (Dec. 13, 1960).

55. Cline, R. W., Fulrath, R. M., and Pask, J. A., "Fundamentals of Glass to Metal Bonding v. Wettability of Iron by Molten Sodium Disilicate", J. Am. Ceram. Soc. 44 423-8 (1961).

56. Cochran, James, "Enameling Metal", U. S. Patent 533,945 (Feb. 12, 1895).

57. Cole, Norman W., "Process for Applying Fused Metal Coating onto Metal Base and Adhesive Used Therein", U. S. 2,694,647 (Nov. 16, 1954).

58. Comstock, G. and Wainer, E., "New Titanium Steel for Vitreous Enameling", Iron Age 155 60-63, 152-3 (1945).

59. Cook, H. L., "Metal Preparation for Vitreous Enameling", Ceramic Forum 1(10) 2 (1935).

60. Cooke, R. D., "Manufacture of Enameled Ware", U. S. Patent 1,316,018 (Sept. 16, 1919).

61. Cooke, R. D., "The Effect of Furnace Atmosphere on the Firing of Enamel", Jour. Amer. Ceram. Soc. 7 277-81 (1924).

62. Corning Glass Works, "Glass to Metal Seal", Canadian Patent 439,321 (Jan. 21, 1947).

63. Craig, Bruce G., "Enamel Bonding by the Use of Arsenic", (A. O. Smith Corp.) U. S. 2,744,843 (May 8, 1956).

64. Crepaz, E., "Refractory Ceramic Coatings for Protection of Metals at High Temperatures", Metallurgia ital., 46 (5, Suppl.) 113-16 (1953).

65. Crystal, H. and Bullock, G., "Oxide Adherence and Nickel Flashing in Vitreous Enameling", J. Am. Ceram. Soc. 42(1) 30-39 (1959).

66. Daley, Charles, "Metal-Glass Seals", U. S. Patent 2,452,519 (Oct. 26, 1948).

67. Danielson, R. R., "The Effect of Variation in the Composition of Ground Coats for Sheet-Iron Enamels", Trans. Amer. Ceram. Soc. 18 343-362 (1916).

68. Danielson, R. R. and Reinecker, H. P., "Wet-Process Enamels for Cast Iron", Bur. Stand., Tech. Paper 246 695-735 (1923).

69. Danielson, R. R. and Koenig, J. H., "A Study of Dry-Process Cast Iron Ground Coat Enamels", Jour. Amer. Ceram. Soc. 30 306-11 (1947).

70. Dartnell, R. C., Fairbanks, H. V. and Koehler, W. A., "Investigation of the Adherence of Glass to Metals and Alloys", J. Am. Ceram. Soc. 34(11) 357-60 (1951).

71. Dechigi, M., "Use of White Arsenic in the Enameling Industry", Arch. Gewerbepath Gewerbshyg, 7 468-476 (1936).

72. De Santis, Vincent J. and Hunter, Fred L., "Method of Forming Protective Coatings for Metallic Surfaces", (International Telephone and Telegraph Corp.) U. S. 2,711,980 (June 28, 1955).

73. Deutsche Gold-und Silber-Scheideanstalt Vorm. Roessler "Ground-Coat Enamels with High Adhesive Power", Belgian Patent 448,622 (Feb., 1943).

74. Deutsche Godl-und Silber-Scheideanstalt Vorm. Roessler, "Manufacture of Firmly Adhering Ground Enamel", (Walter Kerston, inventor), Ger. 806,306, June 14, 1951 (July 31, 1949).

75. Deyrup, Alden J. and Peterson, James H., "Enameling Aluminum-Rich Alloys", (E. I. du Pont de Nemours & Co.) U. S. 2,544,139 March 6, 1951 (July 1, 1947).

76. Dickinson, T. A., "Cerametallic Finishing", Ceram. Age 58(4) 21, 24 (1951).

77. Dickinson, T. A., "Solution Ceramics---a New Temperature-Resistant Surface Coating Technique", Metal Finishing J., 2(17) 145-50 (1956).

78. Dietzel, A., "Drying and Firing of Sheet-Iron Enamels", Glashutte, 65 211 (1935).

79. Dietzel, A., "Possibilities of Replacing Cobalt and Nickel as Adhering Oxides", Sprechsaal 75 460 (1942).

80. Dietzel, A., "Theory of Adherence of Enamel on Iron", Sprechsaal, 78(5) 12 (1945).

81. Dietzel, A., "Sulfide Ground Coats" Ber. deut. Keram. Ges, 26(6/7) 137-41 (1949).

82. Dietzel, A., "Determination of the Adherence of Enamels to Sheet Steel", Ber. deut, Keram. Ges., 26(6/7) 132-37 (1949).

83. Dietzel, A. and Schneider, F., "Cr Content of Sheet Steel for Enameling", Ber. deut. Keram. Ges. u. Ver. deut. Emailfacesleute, 28(2) 81-82 (1951).

84. Douglas, G. S. and Zander, J. M., "X-Ray Diffraction Study of the Oxidation Characteristics of Nickel-Pickled Sheet Iron as Related to Enamel Adherence:, J. Am. Ceram. Soc., 34(2) 52-59 (1951).

85. Doublas, Gordon S. and Zander, Jason M., "X-Ray Study of the reactions at the Steel Surface When Titania Enamel is Applied Directly", J. Am. Ceram. Soc. 35(1) 5-11 (1952).

86. Dowling, W. C., Fairbanks, H. V. and Koehler, W. A., "Study of the Effect of Lubricants on the Adherence of Molten Glass to Heated Metals", J. Am. Ceram. Soc., 33(9) 269-73 (1950).

87. Dreissen, C. G., "Enamels and Ceramic Pigments", Pol. Weekblad, (5, 6, 7) 1918.

88. Ebright, H. E. Clawson, C. D. and Irwin, J. T., "Some Sheet-Iron Ground-Coat Reboil and Bond Studes Using Several Enameling Stocks", Jour. Amer. Ceram. Soc. 16 305-311 (1933).

89. Eisenlohr, "Adherence of Light Ground-Coat on Sheet Iron", Emailletech Monats-Blatter, 9(1) 1-6 (1933).

90. Eisenlohr, "Adhering Interval for Ground-Coat Enamels", Emailletech, Monats-Blatter, 9(2) 11-12 (1933).

91. Ellifson, B. F. and Taylor, W. W., "Surface properties of Fused Salts and Glasses", Jour. Amer. Ceram. Soc., 21 205-220 (1938).

92. Emmel, K., "Cast Iron for Enameling", Giesserei, 26(11) 285-287 (1939).

93. Espe, W. and Knoll, M., "Materials for High-Vacuum Applications", Verlag von Julius Springer, Berling, pp. 322-349 (1936).

94. Eubanks, A. G. and Moore, D. G., "Effect of Oxygen Content of Furnace Atmosphere on Adherence of Vitreous Coatings to Iron", J. Am. Ceram. Soc., 38(7) 226-30 (1955).

95. Eyer, P., "Ground Enamel", U. S. Patent 1,249,937 (Dec. 11, 1917)

96. Eyer, P., "Influence of the Chemical Composition on the Enameling Properties of Cast Iron", Emailletech, Monats-Blatter 8(2) 14 (1933).

97. Eyer, P., "Enamels", British Patent 401,021 (Nov. 9, 1933).

98. Eyer, P., "Enameling Iron", German Patent 613,293 (May 16, 1935).

99. Eyer, P., "Enameling Iron", German Patent 614,220 (June 4, 1935).

100. Eyer, P. "Enameling Iron", German Patent 634,958 (Sept. 7, 1936).

101. Fenton, Walter M., "Porcelain Enamel Compositions Containing Lithium Manganite and/or Lithium Cobalite", (Metalloy Corp.) U. S. 2,487,119, Nov. 8, 1949 (Oct. 4, 1946).

102. Fenton, Walter M. "Porcelain-Enamel Frits Containing Lithium Manganite and (or) Lithium Cobaltite", U. S. Patent 2,487,119 (Nov. 8, 1949).

103. Finley, Jr. J. P., "Nickel Reduction", Clay Prods. News and Ceram. Record, 34(2) 18-19 (1961).

104. Franck, Léon, "Enameling of Iron Sheets Without the Use of Ground Enamel", Fr. 911,857, July 23, 1946 (June 28, 1945).

105. Frank, Karl, "Undercoatings for Fused Enamels on Metal Ware", U. S. Patent 2,351,811 (June 20, 1944).

106. Franke, Ernst A., "Determination of Adherence of Enamels", Sprechsaal 89(21) 495-99 (1956).

107. Franke, Ernst A., "Contribution to Research on the Adherence of Enamels", Sprechsaal, 90(13) 321-23 (14) 347-48 (1957).

108. Franke, Ernst A., "Determination of the Adherence of Sheet Enamel by Measuring the Force Required to Detach the Enamel Coating in Directions at Right Angles to the Surface", Glas-Email-Keramo-Tech., 11(10) 375-79 (1960).

109. Franke, Ernst A., "Determination of the Adherence of Enamel to its Metallic Base", Sprechsaal, 93(15) 407-10 (1960).

110. Franke, Ernst A., "Measurement of the Adherence of Enamel to Sheet Metal", Glas-Email-Keramo-Tech., 12(10) 365-69 (1961).

111. Freedman, Norman S., "Electrodeposited Silver on Steel for Glass-to-Metal Seals", Trans. Electrochem. Soc., 91 325-36 (1947).

112. Frick, Karl, "Investigations of the Density of Acid-resistant Enamel Coatings", Metalloberfläche, 4(7) A97-101 (1950).

113. Friedberg, A. L., "Experiments with White Enamel Directly to Steel", Finish 9(9) 23-26 (1952).

114. Fulrath, Richard M., Mitoff, Stephan P. and Pask, Joseph A., "Fundamentals of Glass-to-Metal Boning: III, Temperature and Pressure Dependence of Wettability of Metals by Glass", J. Am. Ceram. Soc., 40(8) 269-74

115. Gaidos, Frances D., "Effect of Glass Composition on the Wetting of Iron", M. S. Thesis, Univ. of Calif., 1961.

116. Geltman, Gerald L., "Adherence and Thermal Performance of Aluminum Enamels and Coatings", Ceram. Age, 77(4) 73-76 (1961).

117. General Electric Co., Ltd., "Glass and Enamel", British Patent 223,837 (June 24, 1923).

118. Goodman, Gilbert, "Porcelain Enamel", U. S. Patent 2,481,474 (Sept. 6, 1949).

119. Greaves-Walker, Arthur M. K. and King, R. M., "Some Studies on the Adherence of Enamels to Cast Iron", Jour. Amer. Ceram. Soc., 15(9) 476-480 (1932).

120. Gruver, R. M., "Atomistic Approach to the Adhesion to Glass", Glass Ind., 37(2) 77-80, 94, 100-101 (1956).

121. Gulbransen, E. A., "Formation and Stability of Oxide Films", Trans. Electro. Soc., 82 375 (1942).

122. Haase, T., "Joining Ceramics with Glass and Metals. I. Joining Ceramics with Glass. II. Joining Ceramics with Metals", Keram. Rundschau, 50 181-184 (1942).

123. Hadwiger, Hans, "Composition of Sheet Ground-Coat Enamels and Ground-Coat Enameling", Mitt. Ver. deut. Emailfachleute, 1(7) 25-27; (8) 31-33 (1953).

124. Hagan, L. G. and Ravitz, S. F., "Fundamentals of Glass-to-Metal-Bonding: VI. Reaction Between Metallic Iron and Molten Sodium Disilicate", J. Am. Ceram. Soc. 44 428-9 (1961).

125. Hansen, J. E. and Irwin, J. T., "The Use of a Nickel Dip in Enameling Practice", Jour. Amer. Ceram. Soc. 18 225-229 (1935).

126. Harrison, W. N., Moore, D. G. and Richmond J. L., "High Temperature Protection for Mild Steels", Steel, 120(6) 92-92, 120-122 (1947).

127. Hartman, A., "Zircon Enamel", Z anorg, Chem. pp. 178-227 (1909).

128. Hayes, Anson, "Adherence of Porcelain Enamel", "I. Ceram. Ind., 20(1) 10-12 (1933).

129. Hayes, Anson, "Adherence and Reboiling of Porcelain Enamel. II", Ceram. Ind. 20(2) 84-88 (1933).

130. Healy, J. H. and Andrews, A. I., "Cobalt-Reduction Theory for the Adherence of Sheet-Iron Ground Coats", J. Am. Ceram. Soc., 34(7) 207-14 (1951).

131. Healy, J. H. and Andrews, A. I., "Elements of the Third, Fourth, and Fifth Series as Possible Adherence-Promoting Materials for Sheet-Iron Enamels", J. Am. Ceram. Soc., 34(7) 214 (1951).

132. Heimes, Friedrich, "Adherence of Ground Enamels Containing Cobalt and Nickel Oxides", Ceram. Age 25 85-86 (1935).

133. Heimes, Friedrich, "Adherence of Ground Enamels Containing Cobalt and Nickel Oxides", Ceram. Age, 26 480-482 (1935).

134. Heller, Wilhelm, "Considerations and Experiments on the Manufacture of a Light Ground Enamel for Sheet Metal", Sprechsaal, 94(18) 466-68 (1961).

135. Hochwalt, C. A. and Reboulex, H.J., "Enamel Coatings on Metal Articles", U. S. Patent 2,056,399 (Oct. 6, 1936).

136. Hodgdon, Frank B., "Lead Borosilicate Enamel" U. S. Patent 2,481,473 (Sept. 6, 1949).

137. Hofstetter, G. W., "Suggestions on Nickel Pickling", Better Enameling, 3(12) 9 (1932).

138. Holloway, A. J., "Emulsion and Alkaline Cleaning", Finish, 7(1) 53-54, 76 (1950).

139. Hommel, Oscar, "Coating Iron or Steel Articles with Vitreous Enamel", U. S. Patent 1,805,143 (May 12, 1931).

140. The O. Hommel Company, "Vitreous Enameling", British Patent 455,951 (Oct. 30, 1936).

141. Housekeeper, W. G., "The Art of Sealing Base Metal Through Glass", Jour. Amer. Inst. Elec. Eng., 42 870-877 (1923).

142. Houwink, R., "Principles of the Adhesion Phenomenon--An Introduction to the Problems of Adhesion", Kolloid-Z, 151(2) 143-47 (1957).

143. Hubbell, Dean S. and Weaver, Ernest P., "Enameling of Aluminum Alloys", (H. H. Robertson Co.), U. S. 2,932,584, April 12, 1960.

144. Hughes, G. B. and Baker, R. J., "Low Temperature Porcelain Enameling at Frigidaire", Metal Prods. Mfg., 17(1) 38-39 (1960).

145. Huppert, P. A., "Lithium Compounds in Porcelain-Enamel Compositions", Finish, 4(7) 21-22, 52 (1947).

146. Illies, H., "Production of Casts for Enameling", Emailwaren-Ind., 7 115, 124 (1930).

147. Irvine, W. A., "Adherence of Sheet-Steel Ground Coats", Jour. Can. Ceram. Soc., 5 49-52 (1936).

148. Irvine, W. A., "Adherence of Sheet-Steel Ground Coats", Read before Canadian Ceram. Soc. Toronto (Feb., 1936).

149. Jackson, H. A., "Solutions of Water-Insoluble Metaphosphates", U. S. Patent 2,414,742 (Jan. 21, 1947).

150. Jaeger, F. G. Cooke, R. D., Fellows, Roger and Jennings, A., "Enamel Symposium", Jour. Amer. Ceram. Soc., 10(6) 451-456 (1927).

151. Jenny, A. L., "Soldered Ceramic to Metal", Product Eng., 18(12) 154-157 (1947).

152. Johnson, F., "Oxygen and Metals", Foundry Trade Jour. 39(635) 279-280 (1928).

153. Johnson, L. A. and Howe, E. E., "Factors Governing Adherence of Enamels Applied to Sheet Iron", Jour. Amer. Ceram. Soc. 29(10) 296-301 (1946).

154. Karmaus, H. J., "The Base Frit for Cast Iron Enamels", Sprechsaal, 67 4-6 (1934).

155. Karmaus, H. J., "Powdered Enamel for Bath Tubs", Sprechsaal, 67 778-780, 792-797 (1935).

156. Katz, Joseph M. Hurst, Erwin and Jakubczak, Arthur, "Porcelain Enameling", (General Ceramics Corp.) U. S. 2,772,187 (Nov. 27, 1956).

157. Kautz, Karl, "Influence of Furnace Gases in Enameling", Metal Cleaning and Finishing, 8 353-356 (1936).

158. Kautz, Karl, "Discussion of Lord Paper", Jour. Amer. Ceram. Soc., 20 115-120 (1937).

159. Kautz, Karl., "Random Experiments on Enamel Adherence", Jour. Amer. Ceram. Soc., 21 303-307 (1938).

160. Kautz, Karl., "The Importance of Oxidation in Enameling", Better Enameling, 8 23-27 (1938).

161. Kautz, Karl, "Chemical Determination of Metallic Particles and Oxides of Iron, Nickel, and Cobalt in Fired Ground Coats", Jour. Amer. Ceram Soc., 21 307-311 (1938).

162. Kautz, Karl, "Reply of Staley's Discussion of a Critical Analysis of Some Statements and Experiements on the Adherence of Steel Ground-Coats", Jour. Amer. Ceram. Soc., 21 311-315 (1938).

163. Kautz, Karl, "Oxide Film Between Fired Ground-Coat Enamels and Iron", Jour. Amer. Ceram. Soc., 23 283-287 (1940).

164. Kautz, Karl, "Molybdenum in Enamels, I. Adherence Produced by Molybdenum Compounds", Jour. Amer. Ceram. Soc., 23 283-287 (1940).

165. Kautz, Karl, "Molybdenum in Enamels II. Adherence Produced by Soluble and Insoluble Molybdates", Jour. Amer. Ceram. Soc., 25(8) 160-163 (1942).

166. Kautz, Karl, "Enamel Composition Containing Molybdenum", U. S. Patent 2,293,146 (Aug. 18, 1942).

167. Kautz, Karl, "Molybdenum in Enamels, III. Typical Molybdenum Enamels", Jour. Amer. Ceram. Soc., 28 76-82 (1945).

168. Kautz, Karl, Michelott, Joseph E. and Housley, W. Leas, "Physical Effects of Auxiliary Fluxes in Aluminum Enamels", J. Am. Ceram. Soc., 40(1) 24-30 (1957).

169. Keeler, J. H., Chu, P. K. and Davis, H. M., "Role of Nickel in Porcelain Enameling", J. Am. Ceram. Soc., 35(3) 72-75 (1952).

170. Kerkmann, J. and Kerkmann, H., "Enamel Glaze on Iron", German Patent 289,103 (Sept. 11, 1913).

171. Kerstan, Walter, "Blistering and Pin Heads in Wet Cast-Iron Enameling", Ceram. Ind., 16 254-256 (1931).

172. Kerstan, Walter and Kerstan, Oscar, "Defects in Cast Enamels, Their Cause and Prevention, II", Emailwaren-Ind., 9 1-3, 9-10, 25-28, 31-34 (1932).

173. Ketcham, G. W., "Art of Enameling Metalware", U. S. Patent 708,363 (Sept. 2, 1902).

174. Khvass, E. A., "Promoters of Adherence (of Enamel Ground-Coats):, Doklady Akad, Nauk. U.S.S.R. 67, 711-714 (1949).

175. Khvass, E. A., "Activaters of Adherence of Ground Coats", Doklady Akad. Nauk, U.S.S.R. 67(4) 711-14 (1949).

176. Kimpel, Robert F. and Cook, Ralph L., "Factors Influencing Oxidation of Iron During Firing of Ground-Coat Enamels", Jour. Amer. Ceram. Soc., 33 57-62 (1950).

177. King, Jr., B. W., "Enamel Composition", U. S. Patent 2,396,856 (March 19, 1946).

178. King, B. W., Tripp, H. P. and Duckworth, W. H., "Nature of Adherence of Porcelain Enamels to Metals", J. Am. Ceram. Soc., 42(11), 504-25 (1959).

179. King, Burnham W., "New Developments in Porcelain Enameling", Finish, 7(8), 32-35 (1950).

180. King, R. M., "Mechanics of Enamel Adherence VIII (A) Apparatus for Firing Enamels Under Accurate Control of Temperature, Pressure", Jour. Amer. Ceram. Soc. 16, 232-238 (1933).

181. King, R. M., "Mechanics of Enamel Adherence XII. A Chemical and X-Ray Examination of Metallic Precipitates from Enamels Containing Iron and Cobalt Oxides", Jour. Amer. Ceram. Soc., 19, 246-249 (1936).

182. King, R. M., "Resumé of Some Studies on Sheet-Steel Ground-Coat Enamels", Ceram. Age 30, 55-56 (1937).

183. King, R. M., "Mechanics of Enamel Adherence XIII. A Review of Theoretical Explanations for Formation of Metal Particles in Cobalt Ground-Coats and Some Experiments", Jour. Amer. Ceram. Soc., 20, 53-55 (1937).

184. King, R. M., "Mechanics of Enamel-Adherence, XIV. (1) Role of Cobalt Oxide Precipitation During Ground-Coat Firing Cycle, and (2) Determination of Temperature and Time Intervals of Precipitation", Jour. Amer. Ceram. Soc., 26, 41-48 (1943).

185. King, R. M., "Mechanics of Enamel Adherence XV. Influence of Cobalt and Nickel Oxides on Metal Precipitation at Ground-Coat-Iron Interface", Jour. Amer. Ceram. Soc., 26, 358-360 (1943).

186. King, R. M., "Mechanics of Enamel Adherence XVI. Influence of M_nO_2 on Metal Precipitation at Ground-Coat Interface", Jour. Amer. Ceram. Soc., 27, 350-351 (1944).

187. King, R. M., "Nature of Enamel Adherence" Finish, 4 (9), 37-39, 56 (1947).

188, King, Robert M. and Cook, Ralph L., "Wettability in Enamel-Metal Systems", Am. Ceram. Soc. Bull., 36(8), 293-96 (1957).

189. Kingston, W. E., "Low-Expansion Alloys for Glass-to-Metal Seals", Trans. Amer. Soc. Metals 30, 47-67 (1942).

190. Kingston, W. E., "Metal-Glass Seal and Sealing Alloy", U. S. Patent 2,894,919 (Feb. 12, 1946).

191. Kirst, H., "Action of Different Materials on the Adherence of Sheet Enamel", Glashutte, 71, 592-593 (1941).

192. Knochel, W. J. and Aakjer, Jens. J., "Glass-Metal Seals", U. S. Patent 2,482,494 (Sept. 20, 1949).

193. Knochel, W. J. and Aakjer, J. J., "Making Glass Metal Seals", (Westinghouse Electric Corp.) U. S. 2,482,494 (Sept. 20, 1949).

194. Koenig, J. H. Hower, Jr., L. D. and Sosman, R. B., "Refractory Protective Coatings for Metals of Aircraft Power Plants Subjected to Elevated Temperatures", U. S. Air Force, Air Material Command, A. F. Tech. Rept., No. 6071, 13 pp. (July 1950).

195. R. Koepp and Co., "Enamels", British Patent 107,392 (March 28, 1916).

196. Konetschnigg, Anton, "Adhesion of White Ground-Coat in Reference to Iron and Enamel Oxides", Emailewaren-Ind., 6(2), 159-160 (1929).

197. Kreidl, Alexander, "Enameling Ironware", German Patent 545,340 (Oct. 28, 1925).

198. Kreidl, Alexander, "Enameling", German Patent 618,612 (Sept. 12, 1935).

199. Kreidl, Alexander, "Pretreating Ferrous-Metal Surfaces for Enameling", U. S. Patent 2,104,427 (Jan. 4, 1938).

200. Kreidl, Alexander, "Enameling Iron", Australian Patent 144,027 (Dec. 27, 1935).

201. Kreidl, Ignaz, "Enamels on Iron", French Patent 699,975 (Aug. 2, 1930).

202. Kreidl, Ignaz "Enameling Iron", German Patent 663,278 (Aug. 2, 1938).

203. Kreidl, Ignaz, Enameling Iron", Austrian Patent 154,144 (Aug. 25, 1938).

204. Kruger, Otto, "Modern Raw-Material Questions for Enamel", Emailwaren-Ind., 20, 17-20, 21-24, 27-30 (1943).

205. Kruger, Otto, "improvement of the Adhesion of Enamel to Cast Iron", Emailwaren-Ind., 21, 59-61 (1944).

206. Landrum, Robert D., "The Necessity of Cobalt Oxide in Ground-Coat Enamels for Sheet Steel", Trans. Amer. Ceram. Soc., 14, 256-267 (1912).

207. Lang, H., "The Use of Calcium Floride in Enamels", Keram. Rundschau, 39, 163-164 (1931).

208. Lang, H., "Practical Determinations of the Influence of the Firing Process on the Adherence of the Sheet-Ground Enamel", Glashutte, 62(17), 285-287 (1932).

209. Lang, H., "Majolica Enameling According to the Wet and Powder Methods", Glashutee, 63, 204-206 (1933).

210. Lang, H., "Wet-Enameling of Cast Iron Without Using a Cover Enamel", Glashutte, 70, 170-172 (1940).

211. Lang, H., "Conserving the Adherence Oxides Cobalt and Nickel in Enamels", Keram. Rundschau, 48(22), 181-183 (1940).

212. Lang, H., "Boron-Free Frit Base for the Enameling of Cast Iron", Keram. Rundschau, 48, 376-377 (1940).

213. Lang, H., "Smelting Boron-Free Enamels", Glashutte, 71(13), 195-196 (1941).

214. Lange, H., "Improving the Quality of Enamel by Proper Annealing of the Fired Sheet and Cast-Iron Ware", Glashutte, 71, 269-271 (1941).

215. Lang, H., "Unfused Boron Free Ground Enamel", Keram. Rundschau, 49, 58-60 (1941).

216. Lang, Karl, "Enamel", Keram. Z., 7(1), 24-25 (1955).

217. Lauchner, J. H. and Bennett, D. G., "Fatigue and Internal Stress Analysis of Ceramic Coated Metal Composites", PB Rept. 138624, 37 pp., U. S. Govt. Research Repts., 33(1), 67 (1960).

218. Lefort, Henry G., "Ceramic Adhesives" Proc. Porcelain Enamel Inst. Forum, 20, 121-31 (1958).

219. Leichmetau-Verwertungs G.m.b.H., "Enameling Iron", German Patent 585,409 (Oct. 3, 1933).

220. Lemme, W., Salmang, H. and Brink, J., "Investigations on the Adherence of Frit-Ground Enamels to Cast Iron", Emailwaren-Ind., 10, 245-246 (1933).

221. Lemme, W., Salmang, H. and Brink, J., "Researches on the Adherence of Fritted Ground Enamel to Cast Iron", Glashutte, 66, 421-422 (1936).

222. Lewerth, J. and Dietzel, A., "Effect of Fineness of Grinding of a Enamel Upon its Characteristics", Sprechsaal, 74(1) 4-6, (2) 11-13, (3) 19-21 (1941).

223. Linke, Wilhelm, "Preparation of Sheet Metal for Enameling", Emailwaren-Ind., 8, 41-43 (1931).

224. Linz, Arthur, "Molybdenum", Chem. Industries, 48(5), 570-574 (1941).

225. Lord, J. O. and Rueckel, W. C., "Mechanics of Enamel Adherence. I. Technique of Preparing Enamel-Metal Sections for Microscopic Analysis", Jour. Amer. Ceram. Soc., 14, 777-78 (1931).

226. Lucas, Morand D., "Coating Metallic Articles Such as Normalizing Furnace Parts and Retorts for Use at Elevated Temperatures", U. S. Patent 2,300,454 (Nov. 3, 1942).

227. Lusby, Jr., William E., "Process for Enameling Metals", (E. I. du Pont de Nemours & Co.) U. S. 2,768,907 (Oct. 30, 1956).

228. Lynch E. D. and Friedberg, A. L., "Distribution of Crystals in Titania Enamels Fired Directly on Steel", J. Am. Ceram. Soc., 38(8), 257-63 (1955).

229. McHardy, M. E., "Porcelain Enamel Process Defects, Causes and Possible Cures: VIII, Fish Scale, Adherence", Ceram. Ind., 52(3), 80-81 (1949).

230. McHardy, M. E., "Cover-Coat Application Directly on Steel in Refrigeration", Proc. Porcelain Enamel Inst. Forum 12th Forum, 1950, pp. 33-36; Better Enameling, 22(2), 6-7, 35 (1951).

231. McIntyre, Glenn H. and Bryant, Eugene E., "Coating Ferrous Metals with Porcelain Enamels", U. S. Patent 2,321,763 (June 15, 1943).

232. McIntyre, Glenn H., "Preparing Steel for Porcelain Enameling", Steel, 121(3), 102, 112-120 (1947).

233. Marinina, V. T., "Temperature of Adhesion of Glass to Ferrous Metals", Steklo i Keram., 9(8), 8-9 (1952).

234. Marker, Rudolf, "Use of Cobalt Slag as Raw Material for Enamels", Silikatech, 4(10), 446-48 (1953).

235. Marker, Rudolf, "Influence of Some Properties of Enamels on the Quality of Enameled Ware", Glas-Email-Keramo-Tech., 8(7), 249-52 (1957).

236. Marker, Rudolf, "Possibilities of Improving the Adherence of Ground Enamel at Low Firing Temperatures: I.", Sprechsaal, 94(3) 43-44 (4) 65-68 (1961).

237. Matsumoto, Hideo, Yamauchi, Shiro and Nichiyama Goro, "Alumina Base Cermets: I, Adherence Between Alumina and Chromium", Nagoya Gijutsu Shikensho Hokoku, 6(2), 110-14 (1957).

238. Mayer, M. and Haras, B., "The Function of the Ground Enamel", Sprechsaal 43, 727-729 (1911).

239. Mellor, J. W., "Grazing and Peeling of Glazes", Trans, Ceram. Soc., 34, 1-112 (1935).

240. Moizer, Hans, "White Ground Coat", Glashutte, 67, 300-301 (1937).

241. Menzel, F., "Cobalt Oxide, Its Significance in Ground-Coat Enamels", Ceram. Ind., 13, 590-592 (1929).

242. Meures, K. and Zschimmer, E., "Contribution to the Explanation of the Adherence of Enamels to Sheet Steel", Rev. belg ind. verrievas, ceram. email 3(4), 80-82, (5) 101-104, (6) 130-133 (1932).

243. Meures, K. and Zschimmer, E., "The Explanation of the Adhesion of Enamel to Sheet Iron", Sprechsaal, 65, 62-64, 83-85, 98-100, 119-121, 138-139 (1932).

244. Meures, K. and Dietzel, A., "Adherence of Ground Enamel Free from Adhering Oxides", Emailwaren-Ind., 10, 349-355, 390-393 (1933).

245. Miller, Grant E. and Sweo, B. J., "Some Observations on Reactions of Enamel and Iron", Jour. Amer. Ceram. Soc., 33 107-110 (1950).

246. Mitchell, D. W., Mitoff, S. P. Zackay, V. F. and Pask, J. A., "Measurement of Surface Tension of Glasses, I-II", Glass Indus. 33, 453-7, 482, 515-23, (1952).

247. Monack, A. J., "Theory and Practice of Glass-Metal Seals", Glass Ind., 27(8) 389, (9) 446, (10) 502, (11) 556 (1946).

248. Montgomery, Earle T., Welch, Arnold P. and Bitonte, Joseph L., "Method of Applying a Protective Coating to Metal", (Ohio State University Reserach Foundation) U. S. 2,775,531 (Dec. 25, 1956).

249. Montgomery, Earle T., Welch, Arnold P. and Bitonte, Joseph L., "Method of Applying a Protective Coating to Metal", (Ohio State University Research Foundation), U. S. 2,991,191 (July 4, 1961).

250. Moore, D. G. and Eubanks, A. G., "Influence of Copper Ions on Adherence of Vitreous Coatings to Stainless Steel", J. Am. Ceram. Soc., 39(10), 357-61 (1956).

251. Morey, G. W., "The Properties of Glass", Second edition (Rheinhold Publishing Corporation, New York, 1954) pp. 236, 284.

252. Mori, S., "Effect of Variation in the Composition of Ground-Coat Enamel on Its Adherence to Iron", Jour. Jap. Ceram. Ass'n., 343, 233-236 (1921).

253. Morren, G., "Action of Rust on the Adherence of Enamel to Iron Sheet", Ing. Ohim, 27, 1-3 (1943).

254. Morris, W. C., "Coating Ferrous Metal Surfaces", U. S. Patent 2,294,760 (Sept. 1, 1942).

255. Moser, Frank, "Glass Adhesives", Ceram. Age, 60(4), 31-33 (1952).

256. Moser, Frank, "Wetting Phenomena---a Means for Determining Adhesion", Glass Ind., 37(4), 201-203, 228, 232 (1956).

256. Mould, R. E. and Southwick, R. D., "Strength and Static Fatigue of Abraded Glass Under Controlled Ambient Conditions: II. Effect of Various Abrasions and the Universal Fatigue Curve", J. Am. Ceram. Soc. 42, 582-92 (1959).

257. Nakanishi, Kenji and Nakagawa, Yashibumi, "Studies on Enamel Free from Boric Acid and Cobalt", J. Japan. Ceram. Assoc., 51 (606), 348-51 (1943).

258. Nelson, T. W. and Sullivan, J. D., "Production One-Coat Enameling Experiences With Nickel Oxide Coating", Clay Prods. News and Ceram. Record 35(2), 12, 14 (1962).

259. Niedringhaus, F. G. and Niedringhaus, W. T., "Improvement in the Manufacture of Enameled Iron-Ware", U. S. Patent 177,953 (Sept. 28, 1892).

260. Obst, W., "Adherence of Enamel to Metal", Emailwaren-Ind., 13, 262-263 (1936).

261. Obst, W., "Results of New Experiments in Enameling Cast Iron", Emailwaren Ind., 11, 346-347 (1934).

262. Ottersbach, C. A., "Unmelted Ground Enamel", Glashutte, 65, 487 (1935).

263. Pask, Joseph A., "Adherence of Glass to Metal; Better Enameling", 20(11), 6-7, 31 (1949).

264. Pask, J. A. and Fulrath, R. M., "Fundamentals of Glass-to-Metal Bonding: X. Nature of Wetting and Adherence", Institute of Engineering Research, Series No. 48, Issue No. 10, University of California, (Dec. 31, 1960).

265. Permann, J., "Enamel Coatings in Theory and Practice", Berg & Huttenmannisches Jahrbuch, 84(2), 77-82 (1936).

266. Peterson, F. A., "How to Prevent Defects in Porcelain Enameling Hollow Ware: IX, Application--Streaks and Rundowns", Ceram. Ind., 52(4), 96-97 (1949).

267. Pettyjohn, James, "Nickel Treatment of Enameling Iron", Ceram. Forum, 4, 1-4 (1937).

268. Petzold, A., "Titanium Steel in Enamel Technology", Silikattech., 4(5), 202-206 (1953).

269. Petzold, A. and Betzer, H., "Manufacture of Firmly Adhering Ground Enamels with Mineral Stibnite", Silikattech., 4(7), 297-98 (1953).

270. Petzold, Armin and Betzer, Helmut, "Bright Annealing of Sheet Steel and Its Use in Direct One-Coat-White Enameling", Glas-Email-Keram-Tech., 7(8), 284-87 (1956).

271. Petzold, Armin and Betzer, Helmut, "Preparation of a Boron-Free Ground Enamel With Barite as Substitute for Boron", Silikattech., 8(10), 434-36 (1957).

272. Petzold, Armin and Betzer, Helmut, "One-Coat White Enamels Directly on Steel: V, Qualification of White Cover Coat Enamels to be Applied Directly on Enameling Steel Sheets", Sprechsaal, 90(21), 499-502 (1957).

273. Petzold, Armin and Betzer, Helmut, "One-Coat Enamels (Applied) Directly on Steel. VI, Firing of Titanium White Enamels on Uncoated Sheets", Sprechsaal, 91(2), 26-29 (1958).

274. Petzold, Armin and Kruger, Manfred, "Dependence of Sheet Ground Enamel Adherence on the Adherence Addition", Silikattech., 11(6), 267-70 (1960).

275. Pfaudler-Werke, A. G., "Enameling", British Patent 494,383 (October 25, 1938).

276. Plankenhor, W. J., "Refractory Ceramic-Base Coats for Metal", Jour. Amer. Ceram. Soc., 31, 145-53 (1948).

277. Plankenhorn W. J. and Bennett, Dwight G., "Study of Furnace Atmospheres and Induction Heating in the Firing of Porcelain Enamels", U. S. Air Force, Air Research and Der. Comman, WADC Tech. Rept. No. 53-61, 32 pp. (Oct. 1952).

278. Poor & Co., "Enamel Coating for Ferrous Metals", Brit. 634,477, Jan. 25, 1950 (Nov. 24, 1947: June 19, 1941).

279. Poor & Co., "Vitreous Enameling Materials and Processes", Brit. 639,055, May 3, 1950 (May 16, 1947).

280. Porter, B. H., "Painted Porcelain Enamel on Iron", Products Finishing 4(10), 52, 55 (1940).

281. Porter, F. R., "Special Alloy Steel Aids White on Steel Development", Finish 2(1), 27-8 (1945).

282. Porter, Frank R., "Light-Colored Enameled Articles", U. S. Patent 2,495,762 (Jan. 31, 1950).

283. Porter, F. R., "Fabrication and Enameling Performance of Titanium Enameling Steel", Bull. Amer. Ceram. Soc., 25, 259-66 (1946).

284. Porter, F. R., Simons, J. B., Bisbee, R. F. and Van Derau, C.L., "Titanium Enamel Direct to Steel", Better Enameling, 21(4), 6-13 (1950).

285. Priddey, G. C., "The Influence of Cobalt and Nickel in Vitreous-Enamel Ground Coats", Sheet Metal Ind., 23, 2377-84 (1949).

286. Priddey, G. C., "The Influence of Cobalt and Nickel in Vitreous-Enamel Ground Coats", Sheet Metal Ind., 23, 2377-84 (1946).

287. Quimby, E. C., et al, "Improvement in Processes of Enameling Ironware", U. S. Patent 193,422 (July 24, 1877).

288. Rickman, Ernst, "Enamels", British Patent 450,349 (Aug. 13, 1936)

289. Rickman, Ernst, "Enameling Iron & Steel", German Patent 678,372 (July 14, 1939).

290. Richman, Ernst, "Wet Enameling of Iron", German Patent 727,515 (Oct. 1, 1942).

291. Rieser, S., "White Enamel on Steel", U. S. Patent 1,360,317 and 1,360,318 (Nov. 30, 1920).

292. Rion, Richard O., "Evaluation of the Use of the Refractory Oxides Al_2O_3 and SiO_2 in Eliminating a Gas-Produced Enamel Defect", Am. Ceram. Soc. Bull. 33(1) 16-20 (1954).

293. Rosenberg, Jacob E., "Steel Enamel-Coated Ware", U. S. Patent 2,022,434 (Nov. 26, 1935).

294. Rosenberg, J. E., "Steel Enamel Ware", U. S. Patent 2,229,524 (Jan. 21, 1942).

295. Roudnik, J. and Litvin, A. "Adherence of Enamel to Metals", Congr. Chim. Ind., 15th Congress, Brussels, 2, 616-27 (1935).

296. Sasse, Heinrich, "Cracked Cooking Utensels", Emailwaren-Ind., 11, 47-50 (1934).

297. Schultheis, P., "Ground-Coat Enameling on Available Sheets", Ber. deut. Keram. Ges., 26(8/9), 199-205 (1949).

298. Schwartzwalder, Karl and King, R. M., "VI. A Petrographic, Metallographic, and X-Ray Study of Enamel-Metal Contact Zones", Jour. Amer. Ceram. Soc., 15, 483-86 (1932).

299. Scott, W. J., "Glass-to-Metal Seal Design", J. Sci. Instruments, 23, 193-202 (1946).

300. Shartsis, L. and Spinner, S., "Surface Tension of Molten Alkali Silicates", J. Research Natl. Bur. Standards 46, 385-90 (1951).

301. Shartsis, L. and Capps, W., "Surface Tension of Molten Alkali Borates", J. Am. Ceram. Soc., 35, 169-72 (1952).

302. Shaw, Leon I. and Johnson Albert G., "Enameling Articles Such as Metal Signs", U. S. Patent 1,852,759 (April 5, 1932).

303. Shimohira, Takajiro, "Factors Affecting the Adhrence of Ceramic Coatings to Stainless Steel: I, Ceramic Coatings", Yogyo Kyokai Shi, 67(759), 95-102 (1959).

304. Simons, B., "Production of Range Platforms Cover-Coat Enamel Direct to Steel, A Progress Report", Finish, 5(4), 36-37 (1948).

305. Simpson, Harold E., "The Development of an Enamel on a Eutectic Basis", Enamelist, 4, 28-46, 54-5 (1931).

306. Sirovy, G. and Ozolgos, E. P., "Enamel Chipping: The Relationship of Ground Coat Adherence to the Thickness and Yield Value of Sheet Steel", Bull. Amer. Ceram. Soc., 17, 168-70 (1938)

307. Spencer-Strong, George H. and King, R. M., "V. A Study of Enamel-Metal Contact Zones by Chemical Methods", Jour. Amer. Ceram. Soc. 15, 480-488 (1932).

308. Spencer-Strong, G. H., Lord, J. O. and King, R. M., "VII. Further Studies of Enamel-Metal Contact Zones by Microscopic and Metallographic Methods", Jour. Amer. Ceram. Soc., 15, 486-90 (1932).

309. Spencer-Strong, G. H. and King, R. M., "Mechanics of Enamel Adherence. IX Equilbrium Studies in Some Systems of Enamel Glass and Cobalt, Nickel and Iron Oxides", Jour. Amer. Ceram. Soc., 17, 208-14 (1934).

310. Spencer-Strong, G. H. and King, R. M., "Mechanics of Enamel Adherence. X 'The Iron Oxide' Layer in Sheet-Steel Ground-Coats", Jour. Amer. Ceram. Soc., 17, 215-19 (1934).

311. Spichten, H. and Knoebel, R., "Composition for Uniting Glass, Etc., with Metal", French Patent 442,349 (Feb. 29, 1912).

312. Spriggs, R. M. and Friedberg, A. L., "Reaction Kinetics of Porcelain Enamel-Metal Systems", J. Am. Ceram. Soc., 43(5), 252-62 (1960).

313. Staley, Homer F., "Principles of Enameling, V", The Ceramist, 4, 351-62 (1924).

314. Staley, Homer F., "Principles of Enameling. VIII. Ground-Coat Enamels for Dry-Process Enameling of Cast Iron", The Ceramist, 6, 384-95 (1925).

315. Still, Jr., Henry D., "Study of the Oxidation of Steel Plate as Related to Wettability and Adherence of Porcelain Enamel", Am. Ceram. Soc. Bull., 37(1) 22-26 (1958).

316. Stuckert, Ludwig, "The Composition of Enamels; Ground-Coats for Sheet Steel", Ceram. Age, 19, 211-13, 237, 20 15-18, 43 (1932).

317. Stuckert, L., "Influence of the State of Fusion of Enamel Frits on the Properties and Workability of Boron-Free Enamels", Sprechsaal, 76, 297-303, 333-7 (1943).

318. Stuckert, L., Rauter, F. J. and Kastener, J., "Replacement of Fluorspar in Enamel", Emailwaren-Ind., 21, 39-41 (1944).

319. Stuckert, L., "Replacement of Fluorspar in Enamel", Emailwaren-Ind., 21, 49-50 (1944).

320. Stupakoff, S. H. and Precott, Frank R., "Glass-to-Metal Seals, Such as Those of Transformer or Condenser Wires", U. S. Patent 2,318,435 (May 4, 1943).

321. Sturm, R., "Treatment of Sheet Metal Prior to Enameling", Mitt. Ver. deut. Emailfachleute, 5(5) 35-38 (1957).

322. Sullivan, James D., "Direct-on Enameling with an Immediate Catalist Film", Am. Ceram. Soc. Bull., 41(6), 369-73 (1962).

323. Sun, K. H. and Silverman, A., "Glass-Forming Nature of Oxides with Special Reference to Tantala, and Beryllia", Jour. Amer. Ceram. Soc., 25, 97-100 (1942).

324. Symonds, H. H., "Enamel Adhesion", Metal Ind. (London), 78(14), 270 (1951).

325. Tanner, Robert R., "Enameling Metal", Canadian Patent 360,972 (Oct. 6, 1936).

326. Tashiro, Megumi, "Boric Oxide Content in Ground-Coat Enamel", J. Japan. Ceram. Assoc., 57(635), 30-32 (1949)

327. Tashiro, Megumi, "Mechanism of Adherence to Enamel to Steel Surface: I,", J. Japan. Cerem. Assoc., 57(637), 70-71 (1949).

328. Tashiro, Megumi, "Effects of Titanium Oxide on the Properties of Ground-Coat Enamels", J. Ceram. Assoc., Japan, 58(646), 133-34 (1950).

329. Tashiro, Megumi, "Mechanism of Adherence of Enamel to Steel Surface: VI, Iron-Silicate Crystals Appearing at the Iron-Enamel Interface", J. Ceram. Assoc. Japan, 58(648), 204-209 (1950).

330. Tashiro, Megumi, Sakka, Sumio and Teranishi, Hironori, "Effects of Vanadium Oxide on the Adherence of Heal-Resisting Enamel Applied on Nickel-Chrome Stainless-Steel", J. Ceram. Assoc. Japan, 61(689) 537-40 (1953).

331. Taylor, N. W., "The Adherence of Glass to Metals", Glass Ind., 16(8), 243 (1935).

332. Tetrick, James D., "A Study of White Ground Coats", Jour. Amer. Ceram. Soc., 17, 349-56 (1934).

333. Thews, E. R., and Draghincesu, G., "Defects in the Manufacture of Cast Brass for Special Enameling", Metallaberfläche, 5, A76-79 (1951).

334. Thornton, H. Richard, "Bond Strength and Elastic Properties of Ceramic Adhesives", J. Am. Ceram. Soc., 45(5), 201-209 (1962).

335. Thurner and Glaser, G., "Significance of the Adherence Oxides in Grounding Iron Plate", Glashutte, 60, 477-79 (1930).

336. Tickle, W. H. F., Knowles, M. K. and Crystal, H., "Assessment of Adhesion of Vitreous Enamels by Torsion", Inst. Vitreous Enamellers Bull, 5(5), 113-20 (1955).

337. Tostmann, C., "The Function of the Ground Enamel", Keram. Raudschau, 19, 5-6 (1911).

338. Totot-Gibaru, C., "Enameling Metals", British Patent 262,159 (June 16, 1925).

339. Uchida, Tokiji and Arimoto, Kazuo, "Study of Acid-Resisting Enamels", Osaka Industrial Lab., Bull, 4(1), 68 (1923).

340. Uchida, Tokiji, "A Study of Enamel Glaze", Proc. World, Eng. Cong., Tokyo 1929, 31, 316-73 (1931).

341. Uchida, Tokiju and Tomaki, Iumio, "Increasing the Adherence of the Enamel Layer on Enameled-Iron Wares", Repts. Imp. Ind. Research Inst., Osaka, Japan, 16(5), 1-30 (1935).

342. Vereinigte Chem. Fabriken Landau, Kreidl, Heller and Co., "Iron Enamels", German Patent 282,348 (Aug. 10, 1912).

343. Vereinigte Chem. Fabriken, Kreidl, Heller and Co., "Enameling Iron", German Patent 522,472 (Nov. 4, 1923).

344. V., "Developments in Enamel Technique in 1939", Emailwaren-Ind., 17(3-4), 7-8 (1940).

345. Vielhaber, L., "The Behavior of Metal Oxides in Ground Coats on Sheet Metal", Keram. Rundschau, 33, 53-5 (1925).

346. Vielhaber, L., "Nickel Ground and Fishscaling (In Enamels)", Emailwaren-Ind., 7, 337-8 (1930).

347. Vielhaber, L., "Increasing the Adherence of Ground Enamel with Boric Acid", Emailwaren-Inc., 9, 251-2 (1932).

348. Vielhaber, L., "Adherence of Sheet-Iron Enamel", Emaillerie, 2(5), 5-6 (1934).

349. Vielhaber, L., "Lithium Oxide in Enamel", Emailwaren-Ind., 11, 250 (1934).

350. Vielhaber, L., "Ground-Coat Enamels Without Borax", Emailwaren-Ind., 11, 345-6 (1934).

351. Vielhaber, L., "Researches on a White Ground Coat for Sheet Iron", Emailwaren-Ind., 11, 385-7 (1934).

352. Vielhaber, L., "Researches on Enameled Wave", Emailwaren-Ind., 12, 157-58 (1935).

353. Vielhaber, L., "Unfused Ground Sheet-Iron Enamels", Emailwaren-Ind., 13, 129-30 (1936).

354. Vielhaber, L., "Leadless Ground Enamel for Cast-Iron", Emailwaren-Ind., 13, 286-7 (1936).

355. Vielhaber, L., "Ground Enamel on Cast Iron for Majolica Enamels", Emailwaren-Ind., 14, 403-4 (1936).

356. Vielhaber, L., "Quartz and Feldspar in Ground Enamel", Emailwaren-Ind., 14, 330-31 (1937).

357. Vielhaber, L., "Enamel as a Bonding Agent for Ceramic Materials and as Pigment", Emailwaren-Ind., 15(25-26) 176 (1938).

358. Vielhaver, L., "Adhering Power of Enamels on Cast Iron", Emailwaren-Ind., 15, 319-20 (1938).

359. Vielhaber, L., "Formation of Oxides Affects Adherence of Enamels", Emailwaren-Ind., 15 320-21 (1938).

360. Vielhaber, L., "Sheet-Metal Ground Enamels", Emailwaren-Ind., 16, 259-60 (1939).

361. Vielhaber, L., "Molybdenum in Enamels", Emailwaren-Ind., 18, 5 (1941).

362. Vielhaber, L., "Replacing the Adhering Oxide Emailwaren-Ind., 10, 101-102 (1942).

363. Vollrath, A. J., "Enameling Ironware", U. S. Patent 515,507 (Feb. 27, 1894).

364. Volpe, M. L. and Peale, J. A., "Fundamentals of Glass-to-Metal Bonding: IV. Wettability of Gold and Platinum by Molten Sodium Disilicate", J. Am. Ceram. Soc., 42, 102-6 (1959).

365. Vondracek, R., "The Function of the Ground Enamel", Sprechsaal, 44, 115 (1911).

366. Wainer, Eugene and Baldwin, W. J., "Nickel Flashing and Its Relation to Enamel Adherence", Jour. Amer. Ceram. Soc., 28(11), 317-26 (1945).

367. Wainer, Eugene, "Titanium-Stabilized Iron For Enameling", Bull. Amer. Ceram. Soc., 25, 248-59 (1946).

368. Warren, B. E., "Summary of Work on Atomic Arrangement in Glass", Jour. Amer. Ceram. Soc., 24, 256-61 (1941).

369. Wartenberg, H. V., "Wetting by Molten Salts", Angew. Chem., 69(8), 258-62 (1957).

370. Wedlock, A. W. H. and Mycaley Co., Ltd., "Vitreous Material", British Patent 432,424 (July 26, 1935).

371. Wedlock, Albert W. H., "Vitreous Material Suitable for Adhesion to Metals", U. S. Patent 2,032,239 (Feb. 25, 1936).

372. Weinig, R., "Method of Applying Ground Enamel Using Wet Process", (I. G. Farbenindustrie Akt.-Ges.), Swed. 123, 122, Dec. 22, 1942 (Nov. 12, 1942).

373. Weyl, W. A., "Mechanical Strength of Glass", Glass Ind., 27(1), 17 (1946).

374. Weyl, W. A., "The Significance of the Coordination Requirements of the Catious in the Constitution of Glass: I. Basic Concepts and the Constitution of Alkali Silicate Glasses", J. Soc. Glass Technol. 35, 421-47 (1951).

375. Whitbeck, Roland A., "Method of Producing Vitreous Enameled Metal Articles", "Gilron Products Co.), U. S. 2,609,594 (Sept. 7, 1952).

376. White, J., "Adhesion of Enamels to Iron", Foundry Trade Jour., 57, 437-38), 440 (1937).

377. White, James, "Oxidation and Adhesion in Enameling", Ceram. Age, 32, 39-41 (1938).

378. White, J., "Oxidation of Iron and Adhesion of Enamel", Foundry Trade J., 59(1142), 14-16 (1938).

379. White, J., "Adhesion of Enamels to Iron", Proc. Inst. Vitreous Enamelers, 4, 50-63 (1938).

380. White, James, "Oxidation and Adhesion in Enameling", Sheet-Metal Ind., 12, 807-11 (1938).

381. Wiener Email-Und Glaslirfabrick, Schalir and Co., "Enameling Iron", Austrian Patent 140,233 (Jan. 10, 1935).

382. Willis, James B., "New Pickling Compounds", Proc. Porcelain Enamel Inst. Forum, 14, 14 (1952).

383. Witt, L. and King, R. M., "Adherence of Sheet-Steel Ground Coats as Influenced by Titania Mill Additions", Finish, 7(1), 28-9 (1950).

384. Wolfram, H. G. and Tark, R. H., "Some Observation on the Aging of Enamels", Jour. Amer. Ceram. Soc., 10, 334-46 (1927).

385. Wunderlich and Konig G.m.b.H., "Enamels", British Patent 370,565 (Feb. 13, 1930).

386. Zachariasen, W. H., "The Atomic Arrangement in Glass", Jour. Amer. Chem. Soc., 54, 3841-51 (1932).

387. Zackay, Victor F., Mitchell, David W., Mitoff, Stephan P. and Pask, Joseph A., "Fundamentals of Glass-to-Metal Bonding: I. Wettability of Some Group I and Group VIII Metals by Sodium Silicate Glass", J. Am. Ceram. Soc., 36(3), 84-89 (1953).

388. Zademach, E. R. and Clarke, W. W., "Porcelain Enameling Process", (Metalwash Co.) U. S. 2,570,299 (Oct. 9, 1951).

389. Zander, J. M., "Relation Between Deposit and Adherence", Better Enameling, 11(12), 10-13 (1940).

390. Zander, Jason M., "Conservation of Nickel Salts in the Vitreous Enameling Industry", Better Enameling, 21(12), 6-7 (1950).

391. Zhilin, A. E., "Use of Nepheline for Enamels", Keram. i Steklo, 6, 485-8 (1930).

FOOTNOTES

1. James D. Sullivan, "Glass Metal Reactions and Physical Properties of Glass Coatings," Nov. 1980, In Press, p. 20.
2. B. W. King et al, "Nature of Adherence of Porcelain Enamels to Metals," J. Am. Ceram. Soc., Vol. 42, No. 11, (Nov. 1959), p. 506.
3. Ralph L. Cook, "Concepts of Adherence and Bonding Mechanisms in Porcelain Enamels," A. I. Andrews Lecture of the Porcelain Enamel Institute, Nov. 1974, p. 5.
4. Ibid., p. 5.
5. Ibid., p. 1.
6. King, p. 506.
7. Ibid., p. 505.
8. Cook, p. 2.
9. Andrew I. Andrews, Porcelain Enamels, (Champaign, IL: Garrard Press, Publishers, 1961), p. 418.
10. Cook, p. 2.
11. Andrews, p. 418.
12. Ibid., p. 418.
13. Ibid., p. 419.
14. Ibid., p. 418.
15. King, p. 505.
16. Cook, p. 5.
17. Ibid., p. 4.
18. King, p. 525.
19. Ibid., p. 523.

FOOTNOTES (continued)

20. G. S. Douglas and J. M. Zander "X-ray Diffraction Study of the Oxidation Characteristics of Nickel-Pickled Sheet Iron as Related to Enamel Adherence," J. Am. Ceram. Soc., Vol. 34, 1951, p. 52-59.

21. A. J. Nedeljkovic, "Evaluation of the Enamel-Metal Interface by X-ray and Electron Microscopy Techniques," Ph.D. Thesis University of Illinois, 1971, p. 1.

22. D. B. Dove et al, "Chemical Profile of Oxidized Nickel Films," Paper 23-C-74, Am. Ceramic Soc.

23. L. S. O'Bannon, "Review of Tests for the Estimation and Measurement of the Adherence of Porcelain Enamels and Ceramic Coatings to Iron, Steel and Other Metals," Am. Soc. for Testing Materials, 1954.

24. Sullivan, P. 2.

25. Ibid., p. 8.

26. Ibid., p. 11.

27. King, p. 515.

28. Ibid., p. 507-508.

29. Joseph A. Pask and Richard M. Fulrath, "Fundamentals of Glass-to-Metal Bonding: VIII, Nature of Wetting and Adherence," J. Am. Ceram. Soc., Vol. 45, No. 12, Dec. 1962, p. 596.

30. King, p. 524.

31. Richard M. Fulrath et al, "Fundamentals of Glass-to-Metal, Bonding: III, Temperature and Pressure Dependence of Wettability of Metals by Glass," J. Am. Ceram. Soc., Vol. 40, No. 8, August 1957, p. 273.

32. Andrews, p. 414.

33. Ibid., p. 415.

34. Marcus P. Boron and Joseph A. Pask, "Role of Adherence Oxides in the Development of Chemical Bonding at Glass-Metal Interfaces," J. Am. Ceram. Soc., Vol. 49, No. 1, Jan. 1966, p. 6.

35. Ibid., p. 6.

36. Cook, p. 14.

BIBLIOGRAPHY

1. Adams, R. B. and Pask, J. A., "Fundamentals of Glass-to-Metal Bonding: VII. Wettability of Iron by Molten Sodium Silicate Containing Iron Oxide," J. Am. Ceram. Soc. 44, 430-3 (1961).

2. Andrews, Andrew I., Porcelain Enamels, Champaign, IL: Garrard Press, Publishers, 1961.

3. Anusavice, K. J. et al, "Bonding Mechanism Evidence in a Ceramic-Nonprecious Alloy System," J. Biomed. Mater. Res. Vol. 11, p. 701-709.

4. Borom, Marcus P. "Kinetics of Dissolution and Diffusion of the Oxides of Iron in Sodium Disilicate Glass," J. Am. Ceramic Soc. Vol. 51, No. 2, Nov. 1968, p. 490-497.

5. Borom, Marcus P. and Pask, Joseph A., "Role of Adherence Oxides in the Development of Chemical Bonding at Glass-Metal Interfaces," J. Am. Ceram. Soc. Vol. 49, No. 1, Jan. 1966, p. 1-6.

6. Cline, R. W., Fulrath, R. M. and Pask, J. A., "Fundamentals of Glass to Metal Bonding, v. Wettability of Iron by Molten Sodium Disilicate," J. Am. Ceram. Soc. 44, 423-8 (1961).

7. Cook, Ralph L., "Concepts of Adherence and Bonding Mechanisms in Porcelain Enamels," A. I. Andrews Lecture of the Porcelain Enamel Institute, 1974.

8. Dittrich, F. J. et al, "Flame Spray Powder and Process," U. S. 3,617,358 (Sept. 29, 1967).

9. Douglas, G. S. and Zander, J. M., "X-ray Diffraction Study of the Oxidation Characteristics of Nickel-Pickled Sheet Iron as Related to Enamel Adherence," J. Am. Ceram. Soc. Vol. 34, 1951, p. 52-59.

10. Dove, D. B., et al., "Chemical Profile of Oxidized Nickel Films," Paper 23-C-74, Am. Ceramic Soc.

11. Dumbleton, John H., An Introduction to Orthopaedic Materials. Springfield, IL: Charles C. Thomas Publishing Co., 1975.

12. Edmonton, Allen S., Ed., Campbell's Operative Orthopaedics, St. Louis: C. V. Mosby Co., 1980.

13. Eitel, Wilhelm, Silicate Science, New York: Academic Press, 1976.

14. Fulrath, Richard M. Mitoff, Stephan P. and Pask, Joseph, "Fundamentals of Glass-to-Metal Bonding: III, Temperature and Pressure Dependence of Wettability of Metals by Glass," J. Am. Ceram. Soc., 40(8), 269-74

15. Hagan, L. G. and Ravitz, S. F., "Fundamentals of Glass-to-Metal-Bonding: VI. Reaction Between Metallic Iron and Molten Sodium Disilicate" J. Am. Ceram. Soc. 44, 428-9 (1961).

16. Healy, J. H. and Andrews, A. I., "Cobalt-Reduction Theory for the Adherence of Sheet-Iron Ground Coats", J. Am. Ceram. Soc., 34(7), 207-14 (1951).

17. Hench, L. L., "An Investigation of the Bonding Mechanisms at the Interface of a Prosthetic Material," U. S. Army Medical R and D Command Contract No. DA DA 17-70-C-0001, University of Florida, 1972.

18. Hench, L. L., "Analysis of Bioglass Fixation of Hip Prostheses", J. Biomed. Mater. Res., 1977, p. 267-282.

19. Hench, L. L. et al, "Bonding Mechanisms at the Interface of Ceramic Prosthetic Materials," J. Biomed. Res. Symp., 1971, p. 117-141.

20. Kautz, Karl, "Further Data on Enamel Adherence," Jour. Amer. Ceram. Soc., 19, 93-108 (1936).

21. King, B. W., Tripp, H. P. and Duckworth, W. H., "Nature of Adherence of Porcelain Enamels to Metals", J. Am. Ceram. Soc., 43(11), 504-25 (1959).

22. Mac Millan, P. W., Glass-Ceramics, New York: Academic Press, 1964.

23. Mernagh, Laurence R., Enamels: Their Manufacture and Application to Iron and Steel Ware, Philadelphia: J. B. Lippincott Co., 1928.

24. Mitoff, Stephan P., "Fundamentals of Glass-to-Metal Bonding: II Reactions of Tantalum and Sodium Silicate Glass", J. Am. Ceram. Soc. Vol. 40, No. 4. April 1957, p. 118-120.

25. Nedeljkovic, A. J., "Evaluation of the Enamel-Metal Interface by X-ray and Electron Microscopy Techniques," Ph.D. Thesis University of Illinois, 1971, p. 1.

26. O'Bannon, L. S. "Review of Tests for the Estimation and Measurement of the Adherence of Porcelain Enamels and Ceramic Coatings to Iron, Steel and Other Metals," Am. Soc. for Testing Materials, 1954.

27. Pask, J. A. and Fulrath, R. M., "Fundamentals of Glass-to-Metal Bonding: X. Nature of Wetting and Adherence", Institute of Engineering Research, Series No. 48, Issue No. 10, University of California, (Dec. 31, 1960).

28. Piotrowski, George, "Mechanical Studies of the Bone Bioglass Interfacial Bond," J. Biomed. Mater. Res. Symp. 1975, p. 47-61.

29. Richmond, J. C. et al, "Relation Between Roughness of Interface and Adherence of Porcelain Enamel to Steel," Nat. Bur. of Stds #2934, April, 1953.

30. Singer, S. and Singer, J. S., Industrial Ceramics, London: Chapman and Hall Ltd. 1963.

31. Sullivan, James D., "Glass Metal Reactions and Physical Properties of Glass Coatings," A. I. Andrews Lecture of the Porcelain Enamel Institute, 1980 (in press).

32. Volpe, M. L. and Peale, J. A., "Fundamentals of Glass-to-Metal Bonding: IV. Wettability of Gold and Platinum by Molten Sodium Disilicate", J. Am. Ceram. Soc., 42, 102-6 (1959).

33. Zackey, Victor F., Mitchell, David W., Mitoff, Stephan P. and Pask, Joseph A., "Fundamentals of Glass-to-Metal Bonding: I. Wettability of Some Group I and Group VIII Metals by Sodium Silicate Glass", J. Am. Ceram. Soc., 36(3), 84-89 (1953).